

IN VITRO METHODS OF PRODUCING AND IDENTIFYING IMMUNOGLOBULIN MOLECULES IN EUKARYOTIC CELLS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application No. 60/249,268, filed November 17, 2000, U.S. Provisional Application No. 60/262,067, filed January 18, 2001, U.S. Provisional Application No. 60/271,424, filed February 27, 2001, and U.S. Provisional Application No. 60/298,087, filed June 15, 2001, all of which are incorporated herein by reference in their entireties.

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a high efficiency method of expressing immunoglobulin molecules in eukaryotic cells, a method of producing immunoglobulin heavy and light chain libraries for expression in eukaryotic cells, methods of isolating immunoglobulins which bind specific antigens, and immunoglobulins produced by any of these methods.

Related Art

Immunoglobulin Production

[0002] Antibodies of defined specificity are being employed in an increasing number of diverse therapeutic applications.

[0003] Defined antibodies directed against self antigens are of particular value for *in vivo* therapeutic and diagnostic purposes. Many rodent monoclonal antibodies have been isolated using hybridoma technology and utilized for *in vivo* therapeutic and diagnostic purposes in humans. For example, an early application of these mouse monoclonal antibodies was as targeting agents to kill or image tumors (F. H. Deland and D. M. Goldenberg 1982 in 'Radionuclide Imaging' ed.

D. E. Kuhl pp289-297, Pergamon, Paris; R. Levy and R. A. Miller Ann. Rev. Med. 1983, 34 pp107-116). However, the use of such antibodies *in vivo* can lead to problems. The foreign immunoglobulins can elicit an anti-immunoglobulin response which can interfere with therapy (R. A. Miller et al, 1983 Blood 62 988-995) or cause allergic or immune complex hypersensitivity (B. Ratner, 1943, Allergy, Anaphylaxis and Immunotherapy Williams and Wilkins, Baltimore). Accordingly, it is especially important for such applications to develop antibodies that are not themselves immunogenic in host, for example, to develop antibodies against human antigens that are not themselves immunogenic in humans.

[0004] It is a demanding task to isolate an antibody fragment with specificity against self antigen. Animals do not normally produce antibodies to self antigens, a phenomenon called tolerance (Nossal, G. J. *Science* 245:147-153 (1989)). In general, vaccination with a self antigen does not result in production of circulating antibodies. It is therefore difficult to raise antibodies to self antigens.

[0005] Previously, three general strategies have been employed to produce immunoglobulin molecules which specifically recognize "self" antigens. In one approach, rodent antibody sequences have been converted into human antibody sequences, by grafting the specialized complementarity-determining regions (CDR) that comprise the antigen-binding site of a selected rodent monoclonal antibody onto the framework regions of a human antibody (Winter, *et al.*, United Kingdom Patent No. GB2188638B (1987); Reichmann. L., *et al.* *Nature* (London) 332:323-327 (1988); Foote, J., and Winter, G. *J. Mol. Biol.* 224:487-499 (1992)). In this approach, which has been termed antibody humanization, the three CDR loops of each rodent immunoglobulin heavy and light chain are grafted into homologous positions of the four framework regions of a corresponding human immunoglobulin chain. Because some of the framework residues also contribute to antibody affinity, the structure must, in general, be further refined by additional framework substitutions to enhance affinity. This can be a laborious and costly process.

[0006] More recently, transgenic mice have been generated that express human immunoglobulin sequences (Mendez, M.J., *et al.*, *Nat. Genet.* 15:146-156

(1997)). While this strategy has the potential to accelerate selection of human antibodies, it shares with the antibody humanization approach the limitation that antibodies are selected from the available mouse repertoire which has been shaped by proteins encoded in the mouse genome rather than the human genome. This could bias the epitope specificity of antibodies selected in response to a specific antigen. For example, immunization of mice with a human protein for which a mouse homolog exists might be expected to result predominantly in antibodies specific for those epitopes that are different in humans and mice. These may, however, not be the optimal target epitopes.

[0007] An alternative approach, which does not suffer this same limitation, is to screen recombinant human antibody fragments displayed on bacteriophage (Vaughan, T.J., *et al.*, *Nat. Biotechnol.* 14:309-314 (1996); Barbas, C.F., III *Nat. Med.* 1:837-839 (1995); Kay, B.K., *et al.* (eds.) "Phage Display of Peptides and Proteins" Academic Press (1996)) In phage display methods, functional immunoglobulin domains are displayed on the surface of a phage particle which carries polynucleotide sequences encoding them. In typical phage display methods, immunoglobulin fragments, *e.g.*, Fab, Fv or disulfide stabilized Fv immunoglobulin domains are displayed as fusion proteins, *i.e.*, fused to a phage surface protein. Examples of phage display methods that can be used to make the antibodies include those disclosed in Brinkman U. *et al.* (1995) *J. Immunol. Methods* 182:41-50; Ames, R.S. *et al.* (1995) *J. Immunol. Methods* 184:177-186; Kettleborough, C.A. *et al.* (1994) *Eur. J. Immunol.* 24:952-958; Persic, L. *et al.* (1997) *Gene* 187 9-18; Burton, D.R. *et al.* (1994) *Advances in Immunology* 57:191-280; PCT/GB91/01134; WO 90/02809; WO 91/10737; WO 92/01047; WO 92/18619; WO 93/11236; WO 95/15982; WO 95/20401; and U.S. Patents Nos. 5,698,426, 5,223,409, 5,403,484, 5,580,717, 5,427,908, 5,750,753, 5,821,047, 5,571,698, 5,427,908, 5,516,637, 5,780,225, 5,658,727 and 5,733,743 (said references incorporated by reference in their entireties).

[0008] Since phage display methods normally only result in the expression of an antigen-binding fragment of an immunoglobulin molecule, after phage selection, the immunoglobulin coding regions from the phage must be isolated and re-

cloned to generate whole antibodies, including human antibodies, or any other desired antigen binding fragment, and expressed in any desired host including mammalian cells, insect cells, plant cells, yeast, and bacteria. For example, techniques to recombinantly produce Fab, Fab' and F(ab')₂ fragments can also be employed using methods known in the art such as those disclosed in WO 92/22324; Mullinax, R.L. *et al.*, *BioTechniques* 12(6):864-869 (1992); and Sawai, H. *et al.*, *AJRI* 34:26-34 (1995); and Better, M. *et al.*, *Science* 240:1041-1043 (1988) (said references incorporated by reference in their entireties).

[0009] Immunoglobulin libraries constructed in bacteriophage may derive from antibody producing cells of naïve or specifically immunized individuals and could, in principle, include new and diverse pairings of human immunoglobulin heavy and light chains. Although this strategy does not suffer from an intrinsic repertoire limitation, it requires that complementarity determining regions (CDRs) of the expressed immunoglobulin fragment be synthesized and fold properly in bacterial cells. Many antigen binding regions, however, are difficult to assemble correctly as a fusion protein in bacterial cells. In addition, the protein will not undergo normal eukaryotic post-translational modifications. As a result, this method imposes a different selective filter on the antibody specificities that can be obtained.

[0010] There is a need, therefore, for an alternative method to identify immunoglobulin molecules, and antigen-specific fragments thereof, from an unbiased immunoglobulin repertoire that can be synthesized, properly glycosylated and correctly assembled in eukaryotic cells.

[0011] *Eukaryotic Expression Libraries.* A basic tool in the field of molecular biology is the conversion of poly(A)⁺ mRNA to double-stranded (ds) cDNA, which then can be inserted into a cloning vector and expressed in an appropriate host cell. A method common to many cDNA cloning strategies involves the construction of a "cDNA library" which is a collection of cDNA clones derived from the poly(A)⁺ mRNA derived from a cell of the organism of interest. For example, in order to isolate cDNAs which express immunoglobulin genes, a cDNA library might be prepared from pre B cells, B cells, or plasma cells.

Methods of constructing cDNA libraries in different expression vectors, including filamentous bacteriophage, bacteriophage lambda, cosmids, and plasmid vectors, are known. Some commonly used methods are described, for example, in Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual*, 2d Edition, Cold Spring Harbor Laboratory, publisher, Cold Spring Harbor, N.Y. (1990).

[0012] Many different methods of isolating target genes from cDNA libraries have been utilized, with varying success. These include, for example, the use of nucleic acid hybridization probes, which are labeled nucleic acid fragments having sequences complementary to the DNA sequence of the target gene. When this method is applied to cDNA clones in transformed bacterial hosts, colonies or plaques hybridizing strongly to the probe are likely to contain the target DNA sequences. Hybridization methods, however, do not require, and do not measure, whether a particular cDNA clone is expressed. Alternative screening methods rely on expression in the bacterial host, for example, colonies or plaques can be screened by immunoassay for binding to antibodies raised against the protein of interest. Assays for expression in bacterial hosts are often impeded, however, because the protein may not be sufficiently expressed in bacterial hosts, it may be expressed in the wrong conformation, and it may not be processed, and/or transported as it would in a eukaryotic system. Many of these problems have been encountered in attempts to produce immunoglobulin molecules in bacterial hosts, as alluded to above.

[0013] Accordingly, use of mammalian expression libraries to isolate cDNAs encoding immunoglobulin molecules would offer several advantages over bacterial libraries. For example, immunoglobulin molecules, and subunits thereof, expressed in eukaryotic hosts should be functional and should undergo any normal posttranslational modification. A protein ordinarily transported through the intracellular membrane system to the cell surface should undergo the complete transport process. Further, use of a eukaryotic system would make it possible to isolate polynucleotides based on functional expression of eukaryotic RNA or protein. For example, immunoglobulin molecules could be isolated based on their specificity for a given antigen.

[0014] With the exception of some recent lymphokine cDNAs isolated by expression in COS cells (Wong, G. G., *et al.*, *Science* 228:810-815 (1985); Lee, F. *et al.*, *Proc. Natl. Acad. Sci. USA* 83:2061-2065 (1986); Yokota, T., *et al.*, *Proc. Natl. Acad. Sci. USA* 83:5894-5898 (1986); Yang, Y., *et al.*, *Cell* 47:3-10 (1986)), few cDNAs have been isolated from mammalian expression libraries. There appear to be two principal reasons for this: First, the existing technology (Okayama, H. *et al.*, *Mol. Cell. Biol.* 2:161-170 (1982)) for construction of large plasmid libraries is difficult to master, and library size rarely approaches that accessible by phage cloning techniques. (Huynh, T. *et al.*, In: *DNA Cloning Vol. I, A Practical Approach*, Glover, D. M. (ed.), IRL Press, Oxford (1985), pp. 49-78). Second, the existing vectors are, with one exception (Wong, G. G., *et al.*, *Science* 228:810-815 (1985)), poorly adapted for high level expression. Thus, expression in mammalian hosts previously has been most frequently employed solely as a means of verifying the identity of the protein encoded by a gene isolated by more traditional cloning methods.

[0015] Poxvirus Vectors. Poxvirus vectors are used extensively as expression vehicles for protein and antigen expression in eukaryotic cells. The ease of cloning and propagating vaccinia in a variety of host cells has led to the widespread use of poxvirus vectors for expression of foreign protein and as vaccine delivery vehicles (Moss, B., *Science* 252:1662-7 (1991)).

[0016] Large DNA viruses are particularly useful expression vectors for the study of cellular processes as they can express many different proteins in their native form in a variety of cell lines. In addition, gene products expressed in recombinant vaccinia virus have been shown to be efficiently processed and presented in association with MHC class I for stimulation of cytotoxic T cells. The gene of interest is normally cloned in a plasmid under the control of a promoter flanked by sequences homologous to a non-essential region in the virus and the cassette is introduced into the genome via homologous recombination. A panoply of vectors for expression, selection and detection have been devised to accommodate a variety of cloning and expression strategies. However, homologous recombination is an ineffective means of making a recombinant

virus in situations requiring the generation of complex libraries or when the insert DNA is large. An alternative strategy for the construction of recombinant genomes relying on direct ligation of viral DNA "arms" to an insert and the subsequent rescue of infectious virus has been explored for the genomes of poxvirus (Merchlinsky, *et al.*, 1992, Virology 190:522-526; Pfeleiderer, *et al.*, 1995, J. General Virology 76:2957-2962; Scheiflinger, *et al.*, 1992, Proc. Natl. Acad. Sci. USA 89:9977-9981), herpesvirus (Rixon, *et al.*, 1990, J. General Virology 71:2931-2939) and baculovirus (Ernst, *et al.*, 1994, Nucleic Acids Research 22:2855-2856).

[0017] Poxviruses are ubiquitous vectors for studies in eukaryotic cells as they are easily constructed and engineered to express foreign proteins at high levels. The wide host range of the virus allows one to faithfully express proteins in a variety of cell types. Direct cloning strategies have been devised to extend the scope of applications for poxvirus viral chimeras in which the recombinant genomes are constructed *in vitro* by direct ligation of DNA fragments to vaccinia "arms" and transfection of the DNA mixture into cells infected with a helper virus (Merchlinsky, *et al.*, 1992, Virology 190:522-526; Scheiflinger, *et al.*, 1992, Proc. Natl. Acad. Sci. USA 89:9977-9981). This approach has been used for high level expression of foreign proteins (Pfeleiderer, *et al.*, 1995, J. Gen. Virology 76:2957-2962) and to efficiently clone fragments as large as 26 kilobases in length (Merchlinsky, *et al.*, 1992, Virology 190:522-526).

[0018] Naked vaccinia virus DNA is not infectious because the virus cannot utilize cellular transcriptional machinery and relies on its own proteins for the synthesis of viral RNA. Previously, temperature sensitive conditional lethal (Merchlinsky, *et al.*, 1992, Virology 190:522-526) or non-homologous poxvirus fowlpox (Scheiflinger, *et al.*, 1992, Proc. Natl. Acad. Sci. USA 89:9977-9981) have been utilized as helper virus for packaging. An ideal helper virus will efficiently facilitate the production of infectious virus from input DNA, but will not replicate in the host cell or recombine with the vaccinia DNA products. Fowlpox virus is a very useful helper virus for these reasons. It can enter mammalian cells and provide proteins required for the replication of input

vaccinia virus DNA. However, it does not recombine with vaccinia DNA, and infectious fowlpox virions are not produced in mammalian cells. Therefore, it can be used at relatively high multiplicity of infection (MOI).

[0019] Customarily, a foreign protein coding sequence is introduced into the poxvirus genome by homologous recombination with infectious virus. In this traditional method, a previously isolated foreign DNA is cloned in a transfer plasmid behind a vaccinia promoter flanked by sequences homologous to a region in the poxvirus which is non-essential for viral replication. The transfer plasmid is introduced into poxvirus-infected cells to allow the transfer plasmid and poxvirus genome to recombine *in vivo* via homologous recombination. As a result of the homologous recombination, the foreign DNA is transferred to the viral genome.

[0020] Although traditional homologous recombination in poxviruses is useful for expression of previously isolated foreign DNA in a poxvirus, the method is not conducive to the construction of libraries, since the overwhelming majority of viruses recovered have not acquired a foreign DNA insert. Using traditional homologous recombination, the recombination efficiency is in the range of approximately 0.1% or less. Thus, the use of poxvirus vectors has been limited to subcloning of previously isolated DNA molecules for the purposes of protein expression and vaccine development.

[0021] Alternative methods using direct ligation vectors have been developed to efficiently construct chimeric genomes in situations not readily amenable for homologous recombination (Merchlinsky, M. *et al.*, 1992, *Virology* 190:522-526; Scheiflinger, F. *et al.*, 1992, *Proc. Natl. Acad. Sci. USA.* 89:9977-9981). In such protocols, the DNA from the genome is digested, ligated to insert DNA *in vitro*, and transfected into cells infected with a helper virus (Merchlinsky, M. *et al.*, 1992, *Virology* 190:522-526, Scheiflinger, F. *et al.*, 1992, *Proc. Natl. Acad. Sci. USA* 89:9977-9981). In one protocol, the genome was digested at a unique NotI site and a DNA insert containing elements for selection or detection of the chimeric genome was ligated to the genomic arms (Scheiflinger, F. *et al.*, 1992, *Proc. Natl. Acad. Sci. USA.* 89:9977-9981). This direct ligation method was

described for the insertion of foreign DNA into the vaccinia virus genome (Pfleiderer *et al.*, 1995, J. General Virology 76:2957-2962).

[0022] Alternatively, the vaccinia WR genome was modified to produce vNotI/tk by removing the NotI site in the HindIII F fragment and reintroducing a NotI site proximal to the thymidine kinase gene such that insertion of a sequence at this locus disrupts the thymidine kinase gene, allowing isolation of chimeric genomes via use of drug selection (Merchlsinsky, M. *et al.*, 1992, *Virology* 190:522-526). The direct ligation vector vNotI/tk allows one to efficiently clone and propagate previously isolated DNA inserts at least 26 kilobase pairs in length (Merchlsinsky, M. *et al.*, 1992, *Virology*, 190:522-526). Although large DNA fragments are efficiently cloned into the genome, proteins encoded by the DNA insert will only be expressed at the low level corresponding to the thymidine kinase gene, a relatively weakly expressed early class gene in vaccinia. In addition, the DNA will be inserted in both orientations at the NotI site, and therefore might not be expressed at all. Additionally, although the recombination efficiency using direct ligation is higher than that observed with traditional homologous recombination, the resulting titer is relatively low.

[0023] Accordingly, poxvirus vectors were previously not used to identify previously unknown genes of interest from a complex population of clones, because a high efficiency, high titer-producing method of cloning did not exist for poxviruses. More recently, however, the present inventor developed a method for generating recombinant poxviruses using tri-molecular recombination. *See* Zauderer, WO 00/028016, published May 18, 2000, which is incorporated herein by reference in its entirety.

[0024] Tri-molecular recombination is a novel, high efficiency, high titer-producing method for producing recombinant poxviruses. Using the tri-molecular recombination method in vaccinia virus, the present inventor has achieved recombination efficiencies of at least 90%, and titers at least 2 orders of magnitude higher, than those obtained by direct ligation. According to the tri-molecular recombination method, a poxvirus genome is cleaved to produce two nonhomologous fragments or "arms." A transfer vector is produced which carries

the heterologous insert DNA flanked by regions of homology with the two poxvirus arms. The arms and the transfer vector are delivered into a recipient host cell, allowing the three DNA molecules to recombine *in vivo*. As a result of the recombination, a single poxvirus genome molecule is produced which comprises each of the two poxvirus arms and the insert DNA.

SUMMARY OF THE INVENTION

- [0025] In accordance with one aspect of the present invention, there is provided a method of identifying polynucleotides which encode an antigen-specific immunoglobulin molecule, or antigen-specific fragment thereof, from libraries of polynucleotides expressed in eukaryotic cells.
- [0026] Also provided is a method of identifying polynucleotides which encode immunoglobulin molecules, or fragments thereof, which possess altered effector function.
- [0027] Also provided is a method of constructing libraries of polynucleotides encoding immunoglobulin subunit polypeptides in eukaryotic cells using virus vectors, where the libraries are constructed by trimolecular recombination.
- [0028] Further provided are methods of identifying host cells expressing antigen-specific immunoglobulin molecules, or antigen-specific fragments thereof on their surface by selecting and/or screening for antigen-induced cell death, antigen-induced signaling, or antigen-specific binding.
- [0029] Also provided are methods of screening for soluble immunoglobulin molecules, or antigen-specific fragments thereof, expressed from eukaryotic host cells expressing libraries of polynucleotides encoding soluble secreted immunoglobulin molecules, through antigen binding or through detection of an antigen- or organism-specific function of the immunoglobulin molecule.

BRIEF DESCRIPTION OF THE FIGURES

- [0030] FIG. 1. Selection for specific human antibody by antigen-induced apoptosis.
- [0031] FIG. 2A. Preparation of host cells which directly or indirectly undergo cell death in response to antigen cross linking of surface immunoglobulins.
- [0032] FIG. 2B. Validation of modified CH33 host cells designed to undergo CTL-induced lysis or cell death in response to antigen cross linking of surface immunoglobulins.
- [0033] FIG. 3. Construction of pVHE
- [0034] FIG. 4. Construction of pVKE and pVLE
- [0035] FIG. 5. Selection for Specific Human Antibody by Antigen-dependent Adherence
- [0036] FIG. 6. Schematic of the Tri-Molecular Recombination Method.
- [0037] FIG. 7. Nucleotide Sequence of p7.5/tk and pEL/tk promoters. The nucleotide sequence of the promoter and beginning of the thymidine kinase gene for v7.5/tk (SEQ ID NO: 140) and vEL/tk is shown (SEQ ID NO: 142), and the corresponding amino acid sequence including the initiator codon and a portion of the open reading frame, designated wherein as SEQ ID NO: 141 and SEQ ID NO: 143, respectively.
- [0038] FIG. 8. Construction of pVHEs.
- [0039] FIG. 9. Attenuation of poxvirus-mediated cytopathic effects.
- [0040] FIG. 10 Construction of scFv expression vectors.
- [0041] FIG. 11 Construction of pVHE-X-G1.
- [0042] FIG. 12A A modification in the nucleotide sequence of the p7.5/tk (SEQ ID NO:1) vaccinia transfer plasmid. A new vector, p7.5/ATG0/tk (SEQ ID NO:2), derived as described in the text from the p7.5/tk vaccinia transfer plasmid.
- [0043] FIG. 12B A new vector, p7.5/ATG1/tk (SEQ ID NO:3) derived as described in the text from the p7.5/tk vaccinia transfer plasmid.
- [0044] FIG. 12C A new vector, p7.5/ATG2/tk (SEQ ID NO:4) derived as described in the text from the p7.5/tk vaccinia transfer plasmid.

- [0045] FIG. 12D A new vector, p7.5/ATG3/tk (SEQ ID NO:5) derived as described in the text from the p7.5/tk vaccinia transfer plasmid.
- [0046] FIG. 13 Construction of IgM-Fas fusion products.
- [0047] FIG 14. Expression of Ig α and Ig β in the transfected COS7 and HeLaS3 cell lines. Total RNA was isolated from (A) COS7-Ig $\alpha\beta$ -1, (B) COS7-Ig $\alpha\beta$ -2, (C) HeLaS3-Ig $\alpha\beta$ -1 and (D) EBV-transformed human B cells, reverse transcribed into cDNA in the presence or absence of reverse transcriptase, then PCR amplified with the ig α 5'/ig α 3' and ig β 5'/ig β 3' primer sets. PCR products were then analyzed on 0.8% agarose gels. It should be noted that human B cells exhibit alternative splicing for both Ig α and Ig β See, e.g., Hashimoto, S., *et al.*, *Mol. Immunol.* 32:651 (1995).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

- [0048] The present invention is broadly directed to methods of identifying and/or producing functional, antigen-specific immunoglobulin molecules, or antigen-specific fragments (*i.e.*, antigen-binding fragments) thereof, in a eukaryotic system. In addition, the invention is directed to methods of identifying polynucleotides which encode an antigen-specific immunoglobulin molecule, or an antigen-specific fragment thereof, from complex expression libraries of polynucleotides encoding such immunoglobulin molecules or fragments, where the libraries are constructed and screened in eukaryotic host cells. Further embodiments include an isolated antigen-specific immunoglobulin molecule, or antigen-specific fragment thereof, produced by any of the above methods, and a kit allowing production of such isolated immunoglobulins.
- [0049] A particularly preferred aspect of the present invention is the construction of complex immunoglobulin libraries in eukaryotic host cells using poxvirus vectors constructed by trimolecular recombination. The ability to construct complex cDNA libraries in a pox virus based vector and to select and/or screen for specific recombinants on the basis of either antigen induced cell death, antigen induced signaling, or antigen-specific binding can be the basis for identification

of immunoglobulins, particularly human immunoglobulins, with a variety of well-defined specificities in eukaryotic cells. It would overcome the bias imposed by selection of antibody repertoire in rodents or the limitations of synthesis and assembly in phage or bacteria.

[0050] It is to be noted that the term "a" or "an" entity, refers to one or more of that entity; for example, "an immunoglobulin molecule," is understood to represent one or more immunoglobulin molecules. As such, the terms "a" (or "an"), "one or more," and "at least one" can be used interchangeably herein.

[0051] The term "eukaryote" or "eukaryotic organism" is intended to encompass all organisms in the animal, plant, and protist kingdoms, including protozoa, fungi, yeasts, green algae, single celled plants, multi celled plants, and all animals, both vertebrates and invertebrates. The term does not encompass bacteria or viruses. A "eukaryotic cell" is intended to encompass a singular "eukaryotic cell" as well as plural "eukaryotic cells," and comprises cells derived from a eukaryote.

[0052] The term "vertebrate" is intended to encompass a singular "vertebrate" as well as plural "vertebrates," and comprises mammals and birds, as well as fish, reptiles, and amphibians.

[0053] The term "mammal" is intended to encompass a singular "mammal" and plural "mammals," and includes, but is not limited to humans; primates such as apes, monkeys, orangutans, and chimpanzees; canids such as dogs and wolves; felids such as cats, lions, and tigers; equids such as horses, donkeys, and zebras, food animals such as cows, pigs, and sheep; ungulates such as deer and giraffes; rodents such as mice, rats, hamsters and guinea pigs; and bears. Preferably, the mammal is a human subject.

[0054] The terms "tissue culture" or "cell culture" or "culture" or "culturing" refer to the maintenance or growth of plant or animal tissue or cells *in vitro* under conditions that allow preservation of cell architecture, preservation of cell function, further differentiation, or all three. "Primary tissue cells" are those taken directly from tissue, *i.e.*, a population of cells of the same kind performing the same function in an organism. Treating such tissue cells with the proteolytic

enzyme trypsin, for example, dissociates them into individual primary tissue cells that grow or maintain cell architecture when seeded onto culture plates. Cell cultures arising from multiplication of primary cells in tissue culture are called "secondary cell cultures." Most secondary cells divide a finite number of times and then die. A few secondary cells, however, may pass through this "crisis period," after which they are able to multiply indefinitely to form a continuous "cell line." The liquid medium in which cells are cultured is referred to herein as "culture medium" or "culture media." Culture medium into which desired molecules, *e.g.*, immunoglobulin molecules, have been secreted during culture of the cells therein is referred to herein as "conditioned medium."

[0055] The term "polynucleotide" refers to any one or more nucleic acid segments, or nucleic acid molecules, *e.g.*, DNA or RNA fragments, present in a nucleic acid or construct. A "polynucleotide encoding an immunoglobulin subunit polypeptide" refers to a polynucleotide which comprises the coding region for such a polypeptide. In addition, a polynucleotide may encode a regulatory element such as a promoter or a transcription terminator, or may encode a specific element of a polypeptide or protein, such as a secretory signal peptide or a functional domain.

[0056] As used herein, the term "identify" refers to methods in which desired molecules, *e.g.*, polynucleotides encoding immunoglobulin molecules with a desired specificity or function, are differentiated from a plurality or library of such molecules. Identification methods include "selection" and "screening." As used herein, "selection" methods are those in which the desired molecules may be directly separated from the library. For example, in one selection method described herein, host cells comprising the desired polynucleotides are directly separated from the host cells comprising the remainder of the library by undergoing a lytic event and thereby being released from the substrate to which the remainder of the host cells are attached. As used herein, "screening" methods are those in which pools comprising the desired molecules are subjected to an assay in which the desired molecule can be detected. Aliquots of the pools in which the molecule is detected are then divided into successively smaller pools

which are likewise assayed, until a pool which is highly enriched from the desired molecule is achieved. For example, in one screening method described herein, pools of host cells comprising library polynucleotides encoding immunoglobulin molecules are assayed for antigen binding through expression of a reporter molecule.

[0057] *Immunoglobulins.* As used herein, an "immunoglobulin molecule" is defined as a complete, bi-molecular immunoglobulin, *i.e.*, generally comprising four "subunit polypeptides," *i.e.*, two identical heavy chains and two identical light chains. In some instances, *e.g.*, immunoglobulin molecules derived from camelid species or engineered based on camelid immunoglobulins, a complete immunoglobulin molecule may consist of heavy chains only, with no light chains. *See, e.g.*, Hamers-Casterman *et al.*, *Nature* 363:446-448 (1993). Thus, by an "immunoglobulin subunit polypeptide" is meant a single heavy chain polypeptide or a single light chain polypeptide. Immunoglobulin molecules are also referred to as "antibodies," and the terms are used interchangeably herein. An "isolated immunoglobulin" refers to an immunoglobulin molecule, or two or more immunoglobulin molecules, which are substantially removed from the milieu of proteins and other substances, and which bind a specific antigen.

[0058] The heavy chain, which determines the "class" of the immunoglobulin molecule, is the larger of the two subunit polypeptides, and comprises a variable region and a constant region. By "heavy chain" is meant either a full-length secreted heavy chain form, *i.e.*, one that is released from the cell, or a membrane bound heavy chain form, *i.e.*, comprising a membrane spanning domain and an intracellular domain. The membrane spanning and intracellular domains can be the naturally-occurring domains associated with a certain heavy chain, *i.e.*, the domain found on memory B-cells, or it may be a heterologous membrane spanning and intracellular domain, *e.g.*, from a different immunoglobulin class or from a heterologous polypeptide, *i.e.*, a non-immunoglobulin polypeptide. As will become apparent, certain aspects of the present invention are preferably carried out using cell membrane-bound immunoglobulin molecules, while other aspects are preferably carried out with using secreted immunoglobulin molecules,

i.e., those lacking the membrane spanning and intracellular domains. Immunoglobulin "classes" refer to the broad groups of immunoglobulins which serve different functions in the host. For example, human immunoglobulins are divided into five classes, *i.e.*, IgG, comprising a γ heavy chain, IgM, comprising a μ heavy chain, IgA, comprising an α heavy chain, IgE, comprising an ϵ heavy chain, and IgD, comprising a δ heavy chain. Certain classes of immunoglobulins are also further divided into "subclasses." For example, in humans, there are four different IgG subclasses, IgG1, IgG2, IgG3, and IgG4 comprising γ -1, γ -2, γ -3, and γ -4 heavy chains, respectively, and two different IgA subclasses, IgA-1 and IgA-2, comprising α -1 and α -2 heavy chains, respectively. It is to be noted that the class and subclass designations of immunoglobulins vary between animal species, and certain animal species may comprise additional classes of immunoglobulins. For example, birds also produce IgY, which is found in egg yolk.

[0059] By "light chain" is meant the smaller immunoglobulin subunit which associates with the amino terminal region of a heavy chain. As with a heavy chain, a light chain comprises a variable region and a constant region. There are two different kinds of light chains, κ and λ , and a pair of these can associate with a pair of any of the various heavy chains to form an immunoglobulin molecule.

[0060] Immunoglobulin subunit polypeptides each comprise a constant region and a variable region. In most species, the heavy chain variable region, or V_H domain, and the light chain variable region, or V_L domain, combine to form a "complementarity determining region" or CDR, the portion of an immunoglobulin molecule which specifically recognizes an antigenic epitope. In camelid species, however, the heavy chain variable region, referred to as V_{HH} , forms the entire CDR. The main differences between camelid V_{HH} variable regions and those derived from conventional antibodies (V_H) include (a) more hydrophobic amino acids in the light chain contact surface of V_H as compared to the corresponding region in V_{HH} , (b) a longer CDR3 in V_{HH} , and (c) the frequent occurrence of a disulfide bond between CDR1 and CDR3 in V_{HH} . Each complete immunoglobulin molecule comprises two identical CDRs. A large repertoire of

variable regions associated with heavy and light chain constant regions are produced upon differentiation of antibody-producing cells in an animal through rearrangements of a series of germ line DNA segments which results in the formation of a gene which encodes a given variable region. Further variations of heavy and light chain variable regions take place through somatic mutations in differentiated cells. The structure and *in vivo* formation of immunoglobulin molecules is well understood by those of ordinary skill in the art of immunology. Concise reviews of the generation of immunoglobulin diversity may be found, e.g., in Harlow and Lane, *Antibodies, A Laboratory Manual* Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y. (1988) (hereinafter, "Harlow"); and Roitt, *et al.*, *Immunology* Gower Medical Publishing, Ltd., London (1985) (hereinafter, "Roitt"). Harlow and Roitt are incorporated herein by reference in their entireties.

[0061] Immunoglobulins further have several effector functions mediated by binding of effector molecules. For example, binding of the C1 component of complement to an immunoglobulin activates the complement system. Activation of complement is important in the opsonisation and lysis of cell pathogens. The activation of complement also stimulates the inflammatory response and may also be involved in autoimmune hypersensitivity. Further, immunoglobulins bind to cells via the Fc region, with an Fc receptor site on the antibody Fc region binding to an Fc receptor (FcR) on a cell. There are a number of Fc receptors which are specific for different classes of antibody, including, but not limited to, IgG (gamma receptors), IgE (eta receptors), IgA (alpha receptors) and IgM (mu receptors). Binding of antibody to Fc receptors on cell surfaces triggers a number of important and diverse biological responses including engulfment and destruction of antibody-coated particles, clearance of immune complexes, lysis of antibody-coated target cells by killer cells (called antibody-dependent cell-mediated cytotoxicity, or ADCC), release of inflammatory mediators, placental transfer and control of immunoglobulin production.

[0062] Immunoglobulins of the present invention may be from any animal origin including birds, fish, and mammals. Preferably, the antibodies are of human, mouse, dog, cat, rabbit, goat, guinea pig, camel, llama, horse, or chicken origin.

In a preferred aspect of the present invention, immunoglobulins are identified which specifically interact with "self" antigens, *e.g.*, human immunoglobulins which specifically bind human antigens.

[0063] As used herein, an "antigen-specific fragment" of an immunoglobulin molecule is any fragment or variant of an immunoglobulin molecule which remains capable of binding an antigen. Antigen-specific fragments include, but are not limited to, Fab, Fab' and F(ab')₂, Fd, single-chain Fvs (scFv), single-chain immunoglobulins (*e.g.*, wherein a heavy chain, or portion thereof, and light chain, or portion thereof, are fused), disulfide-linked Fvs (sdFv), diabodies, triabodies, tetrabodies, scFv minibodies, Fab minibodies, and dimeric scFv and any other fragments comprising a V_L and a V_H domain in a conformation such that a specific CDR is formed. Antigen-specific fragments may also comprise a V_HH domain derived from a camelid antibody. The V_HH may be engineered to include CDRs from other species, for example, from human antibodies. Alternatively, a human-derived heavy chain V_H fragment may be engineered to resemble a single-chain camelid CDR, a process referred to as "camelization." See, *e.g.*, Davies J., and Riechmann, L., *FEBS Letters* 339:285-290 (1994), and Riechmann, L., and Muyldermans, S., *J. Immunol. Meth.* 231:25-38 (1999), both of which are incorporated herein by reference in their entireties.

[0064] Antigen-specific immunoglobulin fragments, including single-chain immunoglobulins, may comprise the variable region(s) alone or in combination with the entire or partial of the following: a heavy chain constant domain, or portion thereof, *e.g.*, a CH1, CH2, CH3, transmembrane, and/or cytoplasmic domain, on the heavy chain, and a light chain constant domain, *e.g.*, a C_κ or C_λ domain, or portion thereof on the light chain. Also included in the invention are any combinations of variable region(s) and CH1, CH2, CH3, C_κ, C_λ, transmembrane and cytoplasmic domains.

[0065] As is known in the art, Fv comprises a V_H domain and a V_L domain, Fab comprises V_H joined to CH1 and an L chain, a Fab minibody comprises a fusion of CH3 domain to Fab, etc.

[0066] As is known in the art, scFv comprises V_H joined to V_L by a peptide linker, usually 15-20 residues in length, diabodies comprise scFv with a peptide linker about 5 residues in length, triabodies comprise scFv with no peptide linker, tetrabodies comprise scFv with peptide linker 1 residue in length, a scFv minibody comprises a fusion of CH3 domain to scFv, and dimeric scFv comprise a fusion of two scFvs in tandem using another peptide linker (reviewed in Chames and Baty, *FEMS Microbiol. Letts.* 189:1-8 (2000)). Preferably, an antigen-specific immunoglobulin fragment includes both antigen binding domains, *i.e.*, V_H and V_L. Other immunoglobulin fragments are well known in the art and disclosed in well-known reference materials such as those described herein.

[0067] In certain embodiments, the present invention is drawn to methods to identify, *i.e.*, select or alternatively screen for, polynucleotides which singly or collectively encode antigen-specific immunoglobulin molecules, antigen-specific fragments thereof, or immunoglobulin molecules or fragments with specific antigen-related functions. In related embodiments, the present invention is drawn to isolated immunoglobulin molecules encoded by the polynucleotides identified by these methods.

[0068] The preferred methods comprise a two-step screening and/or selection process. In the first step, a polynucleotide encoding a first immunoglobulin subunit, *i.e.*, either a heavy chain or a light chain, is identified from a library of polynucleotides encoding that subunit by introducing the library into a population of eukaryotic host cells, and expressing the immunoglobulin subunit in combination with one or more species of a second immunoglobulin subunit, where the second immunoglobulin subunit is not the same as the first immunoglobulin subunit, *i.e.*, if the first immunoglobulin subunit polypeptide is a heavy chain polypeptide, the second immunoglobulin subunit polypeptide will be a light chain polypeptide.

[0069] Once one or more polynucleotides encoding one or more first immunoglobulin subunit are isolated from the library in the first step, a second immunoglobulin subunit is identified in the second step. Isolated polynucleotides

encoding the isolated first immunoglobulin subunit polypeptide(s) are transferred into and expressed in host cells in which a library of polynucleotides encoding the second immunoglobulin subunit are expressed, thereby allowing identification of a polynucleotide encoding a second immunoglobulin subunit polypeptide which, when combined with the first immunoglobulin subunit identified in the first step, forms a functional immunoglobulin molecule, or fragment thereof, which recognizes a specific antigen and/or performs a specific function.

[0070] Where immunoglobulin fragments are composed of one polypeptide, *i.e.*, a single-chain fragment or a fragment comprising a V_HH domain, and therefore encoded by one polynucleotide, preferred methods comprise a one-step screening and/or selection process. Polynucleotides encoding a single-chain fragment, comprising a heavy chain variable region and a light chain variable region, or comprising a V_HH region, are identified from a library by introducing the library into host cells such as eukaryotic cells and recovering polynucleotides of said library from those host cells which encode immunoglobulin fragments.

[0071] In certain embodiments, particular immunoglobulin molecules are identified through contacting the host cells expressing immunoglobulin molecules on their surface to antigen, which allows for selection and/or screening of antigen-binding cells in a number of different ways as described below. In other embodiments, desired soluble secreted immunoglobulin molecules are identified by assaying pools of conditioned media for desired functional characteristics of the immunoglobulin molecule, *e.g.*, virus neutralization.

[0072] Where the immunoglobulin molecules are bound to the host cell surface, the first step comprises introducing into a population of host cells capable of expressing the immunoglobulin molecule a first library of polynucleotides encoding a plurality of first immunoglobulin subunit polypeptides through operable association with a transcriptional control region, introducing into the same host cells a second library of polynucleotides encoding, through operable association with a transcriptional control region, a plurality of second immunoglobulin subunit polypeptides, permitting expression of immunoglobulin molecules, or antigen-specific fragments thereof, on the membrane surface of the

host cells, contacting the host cells with an antigen, and recovering polynucleotides derived from the first library from those host cells which bind the antigen.

[0073] Where the immunoglobulin molecules are fully secreted into the cell medium, the first step comprises introducing into a population of host cells capable of expressing the immunoglobulin molecule a first library of polynucleotides encoding a plurality of first immunoglobulin subunit polypeptides through operable association with a transcriptional control region, introducing into the same host cells a second library of polynucleotides encoding, through operable association with a transcriptional control region, a plurality of second immunoglobulin subunit polypeptides, permitting expression and secretion of immunoglobulin molecules, or antigen-specific fragments thereof, into the cell medium, assaying aliquots of conditioned medium for desired antigen-related antibody functions, and recovering polynucleotides derived from the first library from those host cell pools grown in conditioned medium in which the desired function was observed.

[0074] As used herein, a "library" is a representative genus of polynucleotides, *i.e.*, a group of polynucleotides related through, for example, their origin from a single animal species, tissue type, organ, or cell type, where the library collectively comprises at least two different species within a given genus of polynucleotides. A library of polynucleotides preferably comprises at least 10, 100, 10^3 , 10^4 , 10^5 , 10^6 , 10^7 , 10^8 , or 10^9 different species within a given genus of polynucleotides. More specifically, a library of the present invention encodes a plurality of a certain immunoglobulin subunit polypeptide, *i.e.*, either a heavy chain subunit polypeptide or a light chain subunit polypeptide. In this context, a "library" of the present invention comprises polynucleotides of a common genus, the genus being polynucleotides encoding an immunoglobulin subunit polypeptide of a certain type and class *e.g.*, a library might encode a human μ , γ -1, γ -2, γ -3, γ -4, α -1, α -2, ϵ , or δ heavy chain, or a human κ or λ light chain. Although each member of any one library of the present invention will encode the same heavy or light chain constant region, the library will collectively comprise

at least two, preferably at least 10, 100, 10^3 , 10^4 , 10^5 , 10^6 , 10^7 , 10^8 , or 10^9 different variable regions *i.e.*, a "plurality" of variable regions associated with the common constant region.

[0075] In other embodiments, the library encodes a plurality of immunoglobulin single-chain fragments which comprise a variable region, such as a light chain variable region or a heavy chain variable region, and preferably comprises both a light chain variable region and a heavy chain variable region. Optionally, such a library comprises polynucleotides encoding an immunoglobulin subunit polypeptide of a certain type and class, or domains thereof.

[0076] In one aspect, the present invention encompasses methods to produce libraries of polynucleotides encoding immunoglobulin subunits. Furthermore, the present invention encompasses libraries of immunoglobulin subunits constructed in eukaryotic expression vectors according to the methods described herein. Such libraries are preferably produced in eukaryotic virus vectors, even more preferably in poxvirus vectors. Such methods and libraries are described herein.

[0077] By "recipient cell" or "host cell" or "cell" is meant a cell or population of cells into which polynucleotide libraries of the present invention are introduced. A host cell of the present invention is preferably a eukaryotic cell or cell line, preferably a plant, animal, vertebrate, mammalian, rodent, mouse, primate, or human cell or cell line. By "a population of host cells" is meant a group of cultured cells into which a "library" of the present invention can be introduced and expressed. Any host cells which will support expression from a given library constructed in a given vector is intended. Suitable and preferred host cells are disclosed herein. Furthermore, certain host cells which are preferred for use with specific vectors and with specific selection and/or screening schemes are disclosed herein. Although it is preferred that a population of host cells be a monoculture, *i.e.*, where each cell in the population is of the same cell type, mixed cultures of cells are also contemplated. Host cells of the present invention may be adherent, *i.e.*, host cells which grow attached to a solid substrate, or, alternatively, the host cells may be in suspension. Host cells may be cells derived from primary tumors, cells derived from metastatic tumors, primary cells, cells

which have lost contact inhibition, transformed primary cells, immortalized primary cells, cells which may undergo apoptosis, and cell lines derived therefrom.

[0078] As noted above, preferred methods to identify immunoglobulin molecules comprise the introduction of a "first" library of polynucleotides into a population of host cells, as well as a "second" library of polynucleotides into the same population of host cells. The first and second libraries are complementary, *i.e.*, if the "first" library encodes immunoglobulin heavy chains, the "second" library will encode immunoglobulin light chains, thereby allowing assembly of immunoglobulin molecules, or antigen-specific fragments thereof, in the population of host cells. Also, as noted above, another method to identify immunoglobulins or immunoglobulin fragments comprises introduction of a single library of polynucleotides encoding single-chain fragments into a population of host cells. The description of polynucleotide libraries, the composition of the polynucleotides in the library, and the polypeptides encoded by the polynucleotides therefore encompass both the polynucleotides which comprise the "first library" and the polynucleotides which comprise the "second library," and the polypeptides encoded thereby. The libraries may be constructed in any suitable vectors, and both libraries may, but need not be, constructed in the same vector. Suitable and preferred vectors for the first and second libraries are disclosed *infra*.

[0079] Polynucleotides contained in libraries of the present invention encode immunoglobulin subunit polypeptides through "operable association with a transcriptional control region." One or more nucleic acid molecules in a given polynucleotide are "operably associated" when they are placed into a functional relationship. This relationship can be between a coding region for a polypeptide and a regulatory sequence(s) which are connected in such a way as to permit expression of the coding region when the appropriate molecules (*e.g.*, transcriptional activator proteins, polymerases, etc.) are bound to the regulatory sequences(s). "Transcriptional control regions" include, but are not limited to promoters, enhancers, operators, and transcription termination signals, and are

included with the polynucleotide to direct its transcription. For example, a promoter would be operably associated with a nucleic acid molecule encoding an immunoglobulin subunit polypeptide if the promoter was capable of effecting transcription of that nucleic acid molecule. Generally, "operably associated" means that the DNA sequences are contiguous or closely connected in a polynucleotide. However, some transcription control regions, *e.g.*, enhancers, do not have to be contiguous.

[0080] By "control sequences" or "control regions" is meant DNA sequences necessary for the expression of an operably associated coding sequence in a particular host organism. The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, and a ribosome binding site. Eukaryotic cells are known to utilize promoters, polyadenylation signals, and enhancers.

[0081] A variety of transcriptional control regions are known to those skilled in the art. Preferred transcriptional control regions include those which function in vertebrate cells, such as, but not limited to, promoter and enhancer sequences from poxviruses, adenoviruses, herpesviruses, *e.g.*, human cytomegalovirus (preferably the intermediate early promoter, preferably in conjunction with intron-A), simian virus 40 (preferably the early promoter), retroviruses (such as Rous sarcoma virus), and picornaviruses (particularly an internal ribosome entry site, or IRES, enhancer region, also referred to herein as a CITE sequence). Other preferred transcriptional control regions include those derived from mammalian genes such as actin, heat shock protein, and bovine growth hormone, as well as other sequences capable of controlling gene expression in eukaryotic cells. Additional suitable transcription control regions include tissue-specific promoters and enhancers as well as inducible promoters (*e.g.*, promoters inducible by tetracycline, and temperature sensitive promoters). As will be discussed in more detail below, especially preferred are promoters capable of functioning in the cytoplasm of poxvirus-infected cells.

[0082] In certain preferred embodiments, each "immunoglobulin subunit polypeptide," *i.e.*, either a "first immunoglobulin subunit polypeptide" or a

"second immunoglobulin subunit polypeptide" comprises (i) a first immunoglobulin constant region selected from the group consisting of a heavy chain constant region, either a membrane bound form of a heavy chain constant region or a fully secreted form of a heavy chain constant region; and a light chain constant region, (ii) an immunoglobulin variable region corresponding to the first constant region, *i.e.*, if the immunoglobulin constant region is a heavy chain constant region, the immunoglobulin variable region preferably comprises a V_H region, and if the immunoglobulin constant region is a light chain constant region, the immunoglobulin variable region preferably comprises a V_L region, and (iii) a signal peptide capable of directing transport of the immunoglobulin subunit polypeptide through the endoplasmic reticulum and through the host cell plasma membrane, either as a membrane-bound or fully secreted heavy chain, or a light chain associated with a heavy chain. Accordingly, through the association of two identical heavy chains and two identical light chains, either a surface immunoglobulin molecule or a fully secreted immunoglobulin molecule is formed.

[0083] Also in certain preferred embodiments in the context of an immunoglobulin fragment, a single-chain fragment comprises an immunoglobulin variable region selected from the group consisting of a heavy chain variable region and a light chain variable region, and preferably comprises both variable regions. If the immunoglobulin fragment comprises both a heavy chain variable region and a light chain variable region, they may be directly joined (*i.e.*, they have no peptide or other linker), or they may be joined by another means. If they are joined by other means, they may be joined directly or by a disulfide bond formed during expression or by a peptide linker, as discussed below. Accordingly, through the association of the heavy chain variable region and the light chain variable region, a CDR is formed.

[0084] The heavy chain variable region and light chain variable region of one single-chain fragment may associate with one another or the heavy chain variable region of one single-chain fragment may associate with a light chain variable region of another single-chain fragment, and vice versa, depending on the type of

linker. In one embodiment, the single-chain fragment also comprises a constant region selected from the group consisting of a heavy chain constant region, or a domain thereof, and a light chain constant region, or a domain thereof. Two single-chain fragments may associate with one another via their constant regions.

[0085] As mentioned above, in certain embodiments, the polynucleotide encoding the light chain variable region and heavy chain variable region of the single-chain fragment encode a linker. The single-chain fragment may comprise a single polypeptide with the sequence V_H -linker- V_L or V_L -linker- V_H . In some embodiments, the linker is chosen to permit the heavy chain and light chain of a single polypeptide to bind together in their proper conformational orientation. See for example, Huston, J.S., et al, *Methods in Enzym.* 203:46-121 (1991). Thus, in these embodiments, the linker should be able to span the 3.5 nm distance between its points of fusion to the variable domains without distortion of the native Fv conformation. In these embodiments, the amino acid residues constituting the linker are such that it can span this distance and should be 5 amino acids or longer. Single-chain fragments with a linker of 5 amino acids form are found in monomer and predominantly dimer form. Preferably, the linker should be at least about 10 or at least about 15 residues in length. In other embodiments, the linker length is chosen to promote the formation of scFv tetramers (tetrabodies), and is 1 amino acid in length. In some embodiments, the variable regions are directly linked (*i.e.*, the single-chain fragment contains no peptide linker) to promote the formation of scFv trimers (triabodies). These variations are well known in the art. (See, for example, Chames and Baty, *FEMS Microbiol. Letts.* 189:1-8 (2000). The linker should not be so long it causes steric interference with the combining site. Thus, it preferably should be about 25 residues or less in length.

[0086] The amino acids of the peptide linker are preferably selected so that the linker is hydrophilic so it does not get buried into the antibody. The linker (Gly-Gly-Gly-Ser)₃ (SEQ ID NO:6) is a preferred linker that is widely applicable to many antibodies as it provides sufficient flexibility. Other linkers include Glu Ser Gly Arg Ser Gly Gly Gly Gly Ser Gly Gly Gly Gly Ser (SEQ ID NO:7), Glu

Gly Lys Ser Ser Gly Ser Gly Ser Glu Ser Lys Ser Thr (SEQ ID NO:8), Glu Gly Lys Ser Ser Gly Ser Gly Ser Glu Ser Lys Ser Thr Gln (SEQ ID NO:9), Glu Gly Lys Ser Ser Gly Ser Gly Ser Glu Ser Lys Val Asp (SEQ ID NO:10), Gly Ser Thr Ser Gly Ser Gly Lys Ser Ser Glu Gly Lys Gly (SEQ ID NO:11), Lys Glu Ser Gly Ser Val Ser Ser Glu Gln Leu Ala Gln Phe Arg Ser Leu Asp (SEQ ID NO:12), and Glu Ser Gly Ser Val Ser Ser Glu Glu Leu Ala Phe Arg Ser Leu Asp (SEQ ID NO:13). Alternatively, a linker such as the (Gly-Gly-Gly-Gly-Ser)₃ (SEQ ID NO:6) linker, although any sequence can be used, is mutagenized or the amino acids in the linker are randomized, and using phage display vectors or the methods of the invention, antibodies with different linkers are screened or selected for the highest affinity or most affect on phenotype. Examples of shorter linkers include fragments of the above linkers, and examples of longer linkers include combinations of the linkers above, combinations of fragments of the linkers above, and combinations of the linkers above with fragments of the linkers above.

[0087] Also preferred are immunoglobulin subunit polypeptides which are variants or fragments of the above-described immunoglobulin subunit polypeptides. Any variants or fragments which result in an antigen binding fragment of an immunoglobulin molecule are contemplated. Such variants may be attached to the host cell surface, *e.g.*, through association with a naturally-occurring transmembrane domain, through a receptor-ligand interaction, or as a fusion with a heterologous transmembrane domain, or may be secreted into the cell medium. Examples of antigen binding fragments of immunoglobulin molecules are described herein.

[0088] In those embodiments where the immunoglobulin subunit polypeptide comprises a heavy chain polypeptide, any immunoglobulin heavy chain, from any animal species, is intended. Suitable and preferred immunoglobulin heavy chains are described herein. Immunoglobulin heavy chains from vertebrates such as birds, especially chickens, fish, and mammals are included, with mammalian immunoglobulin heavy chains being preferred. Examples of mammalian immunoglobulin heavy chains include human, mouse, dog, cat, horse, goat, rat,

sheep, cow, pig, guinea pig, camel, llama, and hamster immunoglobulin heavy chains. Of these, human immunoglobulin heavy chains are particularly preferred. Also contemplated are hybrid immunoglobulin heavy chains comprising portions of heavy chains from one or more species, such as mouse/human hybrid immunoglobulin heavy chains, or "camelized" human immunoglobulin heavy chains. Of the human immunoglobulin heavy chains, preferably, an immunoglobulin heavy chain of the present invention is selected from the group consisting of a μ heavy chain, *i.e.*, the heavy chain of an IgM immunoglobulin, a γ -1 heavy chain, *i.e.*, the heavy chain of an IgG1 immunoglobulin, a γ -2 heavy chain, *i.e.*, the heavy chain of an IgG2 immunoglobulin, a γ -3 heavy chain, *i.e.*, the heavy chain of an IgG3 immunoglobulin, a γ -4 heavy chain, *i.e.*, the heavy chain of an IgG4 immunoglobulin, an α -1 heavy chain, *i.e.*, the heavy chain of an IgA1 immunoglobulin, an α -2 heavy chain, *i.e.*, the heavy chain of an IgA2 immunoglobulin, and ϵ heavy chain, *i.e.*, the heavy chain of an IgE immunoglobulin, and a δ heavy chain, *i.e.*, the heavy chain of an IgD immunoglobulin. In certain embodiments, the preferred immunoglobulin heavy chains include membrane-bound forms of human μ , γ -1, γ -2, γ -3, γ -4, α -1, α -2, ϵ , and δ heavy chains. Especially preferred is a membrane bound form of the human μ heavy chain.

[0089] Membrane bound forms of immunoglobulins are typically anchored to the surface of cells by a transmembrane domain which is made part of the heavy chain polypeptide through alternative transcription termination and splicing of the heavy chain messenger RNA. *See, e.g.*, Roitt at page 9.10. By "transmembrane domain" "membrane spanning region," or related terms, which are used interchangeably herein, is meant the portion of heavy chain polypeptide which is anchored into a cell membrane. Typical transmembrane domains comprise hydrophobic amino acids as discussed in more detail below. By "intracellular domain," "cytoplasmic domain," "cytosolic region," or related terms, which are used interchangeably herein, is meant the portion of the polypeptide which is inside the cell, as opposed to those portions which are either anchored into the cell membrane or exposed on the surface of the cell. Membrane-bound forms of

immunoglobulin heavy chain polypeptides typically comprise very short cytoplasmic domains of about three amino acids. A membrane-bound form of an immunoglobulin heavy chain polypeptide of the present invention preferably comprises the transmembrane and intracellular domains normally associated with that immunoglobulin heavy chain, *e.g.*, the transmembrane and intracellular domains associated with μ and δ heavy chains in pre-B cells, or the transmembrane and intracellular domains associated with any of the immunoglobulin heavy chains in B-memory cells. However, it is also contemplated that heterologous transmembrane and intracellular domains could be associated with a given immunoglobulin heavy chain polypeptide, for example, the transmembrane and intracellular domains of a μ heavy chain could be associated with the extracellular portion of a γ heavy chain. Alternatively, transmembrane and/or cytoplasmic domains of an entirely heterologous polypeptide could be used, for example, the transmembrane and cytoplasmic domains of a major histocompatibility molecule, a cell surface receptor, a virus surface protein, chimeric domains, or synthetic domains.

[0090] In those embodiments where the immunoglobulin subunit polypeptide comprises a light chain polypeptide, any immunoglobulin light chain, from any animal species, is intended. Suitable and preferred immunoglobulin light chains are described herein. Immunoglobulin light chains from vertebrates such as birds, especially chickens, fish, and mammals are included, with mammalian immunoglobulin light chains being preferred. Examples of mammalian immunoglobulin light chains include human, mouse, dog, cat, horse, goat, rat, sheep, cow, pig, guinea pig, and hamster immunoglobulin light chains. Of these, human immunoglobulin light chains are particularly preferred. Also contemplated are hybrid immunoglobulin light chains comprising portions of light chains from one or more species, such as mouse/human hybrid immunoglobulin light chains. Preferred immunoglobulin light chains include human κ and λ light chains. A pair of either light chain may associate with an identical pair of any of the heavy chains to produce an immunoglobulin molecule,

with the characteristic H_2L_2 structure which is well understood by those of ordinary skill in the art.

[0091] According to a preferred aspect of the invention, each member of a library of polynucleotides as described herein, *e.g.*, a first library of polynucleotides or a second library of polynucleotides, comprises (a) a first nucleic acid molecule encoding an immunoglobulin constant region common to all members of the library, and (b) a second nucleic acid molecule encoding an immunoglobulin variable region, where the second nucleic acid molecule is directly upstream of and in-frame with the first nucleic acid molecule. Accordingly, an immunoglobulin subunit polypeptide encoded by a member of a library of polynucleotides of the present invention, *i.e.*, an immunoglobulin light chain or an immunoglobulin heavy chain encoded by such a polynucleotide, preferably comprises an immunoglobulin constant region associated with an immunoglobulin variable region.

[0092] The constant region of a light chain encoded by the "first nucleic acid molecule," comprises about half of the subunit polypeptide and is situated C-terminal, *i.e.*, in the latter half of the light chain polypeptide. A light chain constant region, referred to herein as a C_L constant region, or, more specifically a C_{κ} constant region or a C_{λ} constant region, comprises about 110 amino acids held together in a "loop" by an interchain disulfide bond.

[0093] The constant region of a heavy chain encoded by the "first nucleic acid molecule" comprises three quarters or more of the subunit polypeptide, and is situated in the C-terminal, *i.e.*, in the latter portion of the heavy chain polypeptide. The heavy chain constant region, referred to herein as a C_H constant region, comprises either three or four peptide loops or "domains" of about 110 amino acid each enclosed by interchain disulfide bonds. More specifically, the heavy chain constant regions in human immunoglobulins include a C_{μ} constant region, a C_{δ} constant region, a C_{γ} constant region, a C_{α} constant region, and a C_{ϵ} constant region. C_{γ} , C_{α} , and C_{δ} heavy chains each contain three constant region domains, referred to generally as C_{H1} , C_{H2} , and C_{H3} , while C_{μ} and C_{ϵ} heavy chains contain four constant region domains, referred to generally as C_{H1} , C_{H2} ,

C_H3, and C_H4. Nucleic acid molecules encoding human immunoglobulin constant regions are readily obtained from cDNA libraries derived from, for example, human B cells or their precursors by methods such as PCR, which are well known to those of ordinary skill in the art and further, are disclosed in the Examples, *infra*.

[0094] Immunoglobulin subunit polypeptides of the present invention each comprise an immunoglobulin variable region, encoded by the "second nucleic acid molecule." Within a library of polynucleotides, each polynucleotide will comprise the same constant region, but the library will contain a plurality, *i.e.*, at least two, preferably at least 10, 100, 10³, 10⁴, 10⁵, 10⁶, 10⁷, 10⁸, or 10⁹ different variable regions. As is well known by those of ordinary skill in the art, a light chain variable region is encoded by rearranged nucleic acid molecules, each comprising a light chain V_L region, specifically a V_κ region or a V_λ region, and a light chain J region, specifically a J_κ region or a J_λ region. Similarly, a heavy chain variable region is encoded by rearranged nucleic acid molecules, each comprising a heavy chain V_H region, a D region and J region. These rearrangements take place at the DNA level upon cellular differentiation. Nucleic acid molecules encoding heavy and light chain variable regions may be derived, for example, by PCR from mature B cells and plasma cells which have terminally differentiated to express an antibody with specificity for a particular epitope. Furthermore, if antibodies to a specific antigen are desired, variable regions may be isolated from mature B cells and plasma cells of an animal who has been immunized with that antigen, and has thereby produced an expanded repertoire of antibody variable regions which interact with the antigen. Alternatively, if a more diverse library is desired, variable regions may be isolated from precursor cells, *e.g.*, pre-B cells and immature B cells, which have undergone rearrangement of the immunoglobulin genes, but have not been exposed to antigen, either self or non-self. For example, variable regions might be isolated by PCR from normal human bone marrow pooled from multiple donors. Alternatively, variable regions may be synthetic, for example, made in the laboratory through generation of synthetic oligonucleotides, or may be derived

through *in vitro* manipulations of germ line DNA resulting in rearrangements of the immunoglobulin genes.

[0095] In addition to first and second nucleic acid molecules encoding immunoglobulin constant regions and variable regions, respectively, each member of a library of polynucleotides of the present invention as described above may further comprise a third nucleic acid molecule encoding a signal peptide directly upstream of and in frame with the second nucleic acid molecule encoding the variable region.

[0096] By "signal peptide" is meant a polypeptide sequence which, for example, directs transport of nascent immunoglobulin polypeptide subunit to the surface of the host cells. Signal peptides are also referred to in the art as "signal sequences," "leader sequences," "secretory signal peptides," or "secretory signal sequences." Signal peptides are normally expressed as part of a complete or "immature" polypeptide, and are normally situated at the N-terminus. The common structure of signal peptides from various proteins is commonly described as a positively charged n-region, followed by a hydrophobic h-region and a neutral but polar c-region. In many instances the amino acids comprising the signal peptide are cleaved off the protein once its final destination has been reached, to produce a "mature" form of the polypeptide. The cleavage is catalyzed by enzymes known as signal peptidases. The (-3,-1)-rule states that the residues at positions -3 and -1 (relative to the cleavage site) must be small and neutral for cleavage to occur correctly. See, e.g., McGeoch, *Virus Res.* 3:271-286 (1985), and von Heinje, *Nucleic Acids Res.* 14:4683-4690 (1986).

[0097] All cells, including host cells of the present invention, possess a constitutive secretory pathway, where proteins, including secreted immunoglobulin subunit polypeptides destined for export, are secreted from the cell. These proteins pass through the ER-Golgi processing pathway where modifications may occur. If no further signals are detected on the protein it is directed to the cells surface for secretion. Alternatively, immunoglobulin subunit polypeptides can end up as integral membrane components expressed on the surface of the host cells. Membrane-bound forms of immunoglobulin subunit

polypeptides initially follow the same pathway as the secreted forms, passing through to the ER lumen, except that they are retained in the ER membrane by the presence of stop-transfer signals, or "transmembrane domains." Transmembrane domains are hydrophobic stretches of about 20 amino acid residues that adopt an alpha-helical conformation as they transverse the membrane. Membrane embedded proteins are anchored in the phospholipid bilayer of the plasma membrane. As with secreted proteins, the N-terminal region of transmembrane proteins have a signal peptide that passes through the membrane and is cleaved upon exiting into the lumen of the ER. Transmembrane forms of immunoglobulin heavy chain polypeptides utilize the same signal peptide as the secreted forms.

[0098] A signal peptide of the present invention may be either a naturally-occurring immunoglobulin signal peptide, *i.e.*, encoded by a sequence which is part of a naturally occurring heavy or light chain transcript, or a functional derivative of that sequence that retains the ability to direct the secretion of the immunoglobulin subunit polypeptide that is operably associated with it. Alternatively, a heterologous signal peptide, or a functional derivative thereof, may be used. For example, a naturally-occurring immunoglobulin subunit polypeptide signal peptide may be substituted with the signal peptide of human tissue plasminogen activator or mouse β -glucuronidase.

[0099] Signal sequences, transmembrane domains, and cytosolic domains are known for a wide variety of membrane bound proteins. These sequences may be used accordingly, either together as pairs (*e.g.*, signal sequence and transmembrane domain, or signal sequence and cytosolic domain, or transmembrane domain and cytosolic domain) or threesomes from a particular protein, or with each component being taken from a different protein, or alternatively, the sequences may be synthetic, and derived entirely from consensus as artificial delivery domains, as mentioned above.

[0100] Particularly preferred signal sequences and transmembrane domains include, but are not limited to, those derived from CD8, ICAM-2, IL-8R, CD4 and LFA-1. Additional useful sequences include sequences from: 1) class I

integral membrane proteins such as IL-2 receptor beta-chain (residues 1-26 are the signal sequence, 241-265 are the transmembrane residues; see Hatakeyama et al, Science 244:551 (1989) and von Heijne et al, Eur. J. Biochem. 174:671 (1988)) and insulin receptor beta-chain (residues 1-27 are the signal, 957-959, are the transmembrane domain and 960-1382 are the cytoplasmic domain; see Hatakeyama *supra*, and Ebina *et al.*, Cell 40:747 (1985)); 2) class II integral membrane proteins such as neutral endopeptidase (residues 29-51 are the transmembrane domain, 2-28 are the cytoplasmic domain; see Malfroy *et al.*, Biochem. Biophys. Res. Commun. 144:59 (1987)); 3) type III proteins such as human cytochrome P450 NF25 (Hatakeyama, *supra*); and 4) type IV proteins such as human P-glycoprotein (Hatakeyama, *supra*). In this alternative, CD8 and ICAM-2 are particularly preferred. For example, the signal sequences from CD8 and ICAM-2 lie at the extreme 5' end of the transcript. These consist of the amino acids 1-32 in the case of CD8 (Nakauchi *et al.*, PNAS USA 82:5126 (1985)) and 1-21 in the case of ICAM-2 (Staunton *et al.*, Nature (London) 339:61 (1989)). These transmembrane domains are encompassed by amino acids 145-195 from CD8 (Nakauchi, *supra*) and 224-256 from ICAM-2 (Staunton, *supra*).

[0101] Alternatively, membrane anchoring domains include the GPI anchor, which results in a covalent bond between the molecule and the lipid bilayer via a glycosyl-phosphatidylinositol bond for example in DAF (see Homans *et al.*, Nature 333(6170):269-72 (1988), and Moran *et al.*, J. Biol. Chem. 266:1250 (1991)). In order to do this, the GPI sequence from Thy-1 can be cassetted 3' of the immunoglobulin or immunoglobulin fragment in place of a transmembrane sequence.

[0102] Similarly, myristylation sequences can serve as membrane anchoring domains. It is known that the myristylation of c-src recruits it to the plasma membrane. This is a simple and effective method of membrane localization, given that the first 14 amino acids of the protein are solely responsible for this function (see Cross *et al.*, Mol. Cell. Biol. 4(9) 1834 (1984); Spencer *et al.*, Science 262:1019 1024 (1993)). This motif has already been shown to be effective in the localization of reporter genes and can be used to anchor the zeta

chain of the TCR. This motif is placed 5' of the immunoglobulin or immunoglobulin fragment in order to localize the construct to the plasma membrane. Other modifications such as palmitoylation can be used to anchor constructs in the plasma membrane; for example, palmitoylation sequences from the G protein-coupled receptor kinase GRK6 sequence (Stoffel et al, J. Biol. Chem 269:27791 (1994)); from rhodopsin (Barnstable *et al.*, J. Mol. Neurosci. 5(3):207 (1994)); and the p21 H-ras 1 protein (Capon *et al.*, Nature 302:33 (1983)).

[0103] In addition to first and second nucleic acid molecules encoding immunoglobulin constant regions and variable regions, respectively, each member of a library of polynucleotides of the present invention as described above may further comprise additional nucleic acid molecule encoding heterologous polypeptides. Such additional polynucleotides may be in addition to or as an alternative of the third nucleic acid molecule encoding a signal peptide. Such additional nucleic acid molecules encoding heterologous polypeptides may be upstream of or downstream from the nucleic acid molecules encoding the variable chain region or the heavy chain region.

[0104] A heterologous polypeptide encoded by an additional nucleic acid molecule may be a rescue sequence. A rescue sequence is a sequence which may be used to purify or isolate either the immunoglobulin or fragment thereof or the polynucleotide encoding it. Thus, for example, peptide rescue sequences include purification sequences such as the 6-His tag for use with Ni affinity columns and epitope tags for detection, immunoprecipitation, or FACS (fluorescence-activated cell sorting). Suitable epitope tags include myc (for use with commercially available 9E10 antibody), the BSP biotinylation target sequence of the bacterial enzyme BirA, flu tags, LacZ, and GST. The additional nucleic acid molecule may also encode a peptide linker.

[0105] In a preferred embodiment, combinations of heterologous polypeptides are used. Thus, for example, any number of combinations of signal sequences, rescue sequences, and stability sequences may be used, with or without linker sequences. One can cassette in various fusion polynucleotides encoding

heterologous polypeptides 5' and 3' of the immunoglobulin or fragment thereof-encoding polynucleotide. As will be appreciated by those in the art, these modules of sequences can be used in a large number of combinations and variations.

[0106] The polynucleotides comprised in the first and second libraries are introduced into suitable host cells. Suitable host cells are characterized by being capable of expressing immunoglobulin molecules attached to their surface. Polynucleotides may be introduced into host cells by methods which are well known to those of ordinary skill in the art. Suitable and preferred introduction methods are disclosed herein.

[0107] As is easily appreciated, introduction methods vary depending on the nature of the vector in which the polynucleotide libraries are constructed. For example, DNA plasmid vectors may be introduced into host cells, for example, by lipofection (such as with anionic liposomes (*see, e.g.,* Felgner *et al.*, 1987 *Proc. Natl. Acad. Sci. U.S.A.* 84:7413 or cationic liposomes (*see, e.g.,* Brigham, K.L. *et al. Am. J Med Sci.* 298(4):278-282(1989); U.S. Patent No. 4,897,355 (Eppstein, *et al.*)), by electroporation, by calcium phosphate precipitation (*see generally, Sambrook et al., Molecular Cloning: A Laboratory Manual*, 2nd Ed., Cold Spring Harbor Laboratory, Cold Spring Harbor, New York, 1989), by protoplast fusion, by spheroplast fusion, or by the DEAE dextran method (Sussman *et al.*, *Cell. Biol.* 4:1641-1643 (1984)). The above references are incorporated herein by reference in their entireties.

[0108] When the selected method is lipofection, the nucleic acid can be complexed with a cationic liposome, such as DOTMA:DOPE, DOTMA, DOPE, DC-cholesterol, DOTAP, Transfectam® (Promega), Tfx® (Promega), LipoTAXI™ (Stratagene), PerFect Lipid™ (Invitrogen), SuperFect™ (Qiagen). When the nucleic acid is transfected via an anionic liposome, the anionic liposome can encapsulate the nucleic acid. Preferably, DNA is introduced by liposome-mediated transfection using the manufacturer's protocol (such as for Lipofectamine; Life Technologies Incorporated).

[0109] Where the plasmid is a virus vector, introduction into host cells is most conveniently carried out by standard infection. However, in many cases viral nucleic acids may be introduced into cells by any of the methods described above, and the viral nucleic acid is "infectious," *i.e.*, introduction of the viral nucleic acid into the cell, without more, is sufficient to allow the cell to produce viable progeny virus particles. It is noted, however, that certain virus nucleic acids, for example, poxvirus nucleic acids, are not infectious, and therefore must be introduced with additional elements provided, for example, by a virus particle enclosing the viral nucleic acid, by a cell which has been engineered to produce required viral elements, or by a helper virus.

[0110] The first and second libraries of polynucleotides may be introduced into host cells in any order, or simultaneously. For example, if both the first and second libraries of polynucleotides are constructed in virus vectors, whether infectious or inactivated, the vectors may be introduced by simultaneous infection as a mixture, or may be introduced in consecutive infections. If one library is constructed in a virus vector, and the other is constructed in a plasmid vector, introduction might be carried out most conveniently by introduction of one library before the other.

[0111] Following introduction into the host cells of the first and second libraries of polynucleotides, expression of immunoglobulin molecules, or antigen-specific fragments thereof, is permitted to occur either on the membrane surface of said host cells, or through secretion into the cell medium. By "permitting expression" is meant allowing the vectors which have been introduced into the host cells to undergo transcription and translation of the immunoglobulin subunit polypeptides, preferably allowing the host cells to transport fully assembled immunoglobulin molecules, or antigen-specific fragments thereof, to the membrane surface or into the cell medium. Typically, permitting expression requires incubating the host cells into which the polynucleotides have been introduced under suitable conditions to allow expression. Those conditions, and the time required to allow expression will vary based on the choice of host cell and the choice of vectors, as is well known by those of ordinary skill in the art.

[0112] In certain embodiments, host cells which have been allowed to express immunoglobulin molecules on their surface, or soluble immunoglobulin molecules secreted into the cell medium are then contacted with an antigen. As used herein, an "antigen" is any molecule that can specifically bind to an antibody, immunoglobulin molecule, or antigen-specific fragment thereof. By "specifically bind" is meant that the antigen binds to the CDR of the antibody. The portion of the antigen which specifically interacts with the CDR is an "epitope," or an "antigenic determinant." An antigen may comprise a single epitope, but typically, an antigen comprises at least two epitopes, and can include any number of epitopes, depending on the size, conformation, and type of antigen.

[0113] Antigens are typically peptides or polypeptides, but can be any molecule or compound. For example, an organic compound, *e.g.*, dinitrophenol or DNP, a nucleic acid, a carbohydrate, or a mixture of any of these compounds either with or without a peptide or polypeptide can be a suitable antigen. The minimum size of a peptide or polypeptide epitope is thought to be about four to five amino acids. Peptide or polypeptide epitopes preferably contain at least seven, more preferably at least nine and most preferably between at least about 15 to about 30 amino acids. Since a CDR can recognize an antigenic peptide or polypeptide in its tertiary form, the amino acids comprising an epitope need not be contiguous, and in some cases, may not even be on the same peptide chain. In the present invention, peptide or polypeptide antigens preferably contain a sequence of at least 4, at least 5, at least 6, at least 7, more preferably at least 8, at least 9, at least 10, at least 15, at least 20, at least 25, and, most preferably, between about 15 to about 30 amino acids. Preferred peptides or polypeptides comprising, or alternatively consisting of, antigenic epitopes are at least 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, or 100 amino acid residues in length. The antigen may be in any form and may be free, for example dissolved in a solution, or may be attached to any substrate. Suitable and preferred substrates are disclosed herein. In certain embodiments, an antigen may be part of an antigen-expressing presenting cell as described in more detail below.

[0114] It is to be understood that immunoglobulin molecules specific for any antigen may be produced according to the methods of the present invention. Preferred antigens are "self" antigens, *i.e.*, antigens derived from the same species as the immunoglobulin molecules produced. As an example, it might be desired to produce human antibodies directed to human tumor antigens such as, but not limited to, a CEA antigen, a GM2 antigen, a Tn antigen, an sTn antigen, a Thompson-Friedenreich antigen (TF), a Globo H antigen, an Le(y) antigen, a MUC1 antigen, a MUC2 antigen, a MUC3 antigen, a MUC4 antigen, a MUC5AC antigen, a MUC5B antigen, a MUC7 antigen, a carcinoembryonic antigen, a beta chain of human chorionic gonadotropin (hCG beta) antigen, a HER2/neu antigen, a PSMA antigen, a EGFRvIII antigen, a KSA antigen, a PSA antigen, a PSCA antigen, a GP100 antigen, a MAGE 1 antigen, a MAGE 2 antigen, a TRP 1 antigen, a TRP 2 antigen, and a tyrosinase antigen. Other desired "self" antigens include, but are not limited to, cytokines, receptors, ligands, glycoproteins, and hormones.

[0115] It is also contemplated to produce antibodies directed to antigens on infectious agents. Examples of such antigens include, but are not limited to, bacterial antigens, viral antigens, parasite antigens, and fungal antigens. Examples of viral antigens include, but are not limited to, adenovirus antigens, alphavirus antigens, calicivirus antigens, *e.g.*, a calicivirus capsid antigen, coronavirus antigens, distemper virus antigens, Ebola virus antigens, enterovirus antigens, flavivirus antigens, hepatitis virus (A-E) antigens, *e.g.*, a hepatitis B core or surface antigen, herpesvirus antigens, *e.g.*, a herpes simplex virus or varicella zoster virus glycoprotein antigen, immunodeficiency virus antigens, *e.g.*, a human immunodeficiency virus envelope or protease antigen, infectious peritonitis virus antigens, influenza virus antigens, *e.g.*, an influenza A hemagglutinin or neuraminidase antigen, leukemia virus antigens, Marburg virus antigens, oncogenic virus antigens, orthomyxovirus antigens, papilloma virus antigens, parainfluenza virus antigens, *e.g.*, hemagglutinin/neuraminidase antigens, paramyxovirus antigens, parvovirus antigens, pestivirus antigens, picorna virus antigens, *e.g.*, a poliovirus capsid antigen, rabies virus antigens,

e.g., a rabies virus glycoprotein G antigen, reovirus antigens, retrovirus antigens, rotavirus antigens, as well as other cancer-causing or cancer-related virus antigens.

[0116] Examples of bacterial antigens include, but are not limited to, *Actinomyces*, antigens *Bacillus* antigens, *Bacteroides* antigens, *Bordetella* antigens, *Bartonella* antigens, *Borrelia* antigens, e.g., a *B. bergdorferi* OspA antigen, *Brucella* antigens, *Campylobacter* antigens, *Capnocytophaga* antigens, *Chlamydia* antigens, *Clostridium* antigens, *Corynebacterium* antigens, *Coxiella* antigens, *Dermatophilus* antigens, *Enterococcus* antigens, *Ehrlichia* antigens, *Escherichia* antigens, *Francisella* antigens, *Fusobacterium* antigens, *Haemobartonella* antigens, *Haemophilus* antigens, e.g., *H. influenzae* type b outer membrane protein antigens, *Helicobacter* antigens, *Klebsiella* antigens, L-form bacteria antigens, *Leptospira* antigens, *Listeria* antigens, *Mycobacteria* antigens, *Mycoplasma* antigens, *Neisseria* antigens, *Neorickettsia* antigens, *Nocardia* antigens, *Pasteurella* antigens, *Peptococcus* antigens, *Peptostreptococcus* antigens, *Pneumococcus* antigens, *Proteus* antigens, *Pseudomonas* antigens, *Rickettsia* antigens, *Rochalimaea* antigens, *Salmonella* antigens, *Shigella* antigens, *Staphylococcus* antigens, *Streptococcus* antigens, e.g., *S. pyogenes* M protein antigens, *Treponema* antigens, and *Yersinia* antigens, e.g., *Y. pestis* F1 and V antigens.

[0117] Examples of fungal antigens include, but are not limited to, *Absidia* antigens, *Acremonium* antigens, *Alternaria* antigens, *Aspergillus* antigens, *Basidiobolus* antigens, *Bipolaris* antigens, *Blastomyces* antigens, *Candida* antigens, *Coccidioides* antigens, *Conidiobolus* antigens, *Cryptococcus* antigens, *Curvalaria* antigens, *Epidermophyton* antigens, *Exophiala* antigens, *Geotrichum* antigens, *Histoplasma* antigens, *Madurella* antigens, *Malassezia* antigens, *Microsporum* antigens, *Moniliella* antigens, *Mortierella* antigens, *Mucor* antigens, *Paecilomyces* antigens, *Penicillium* antigens, *Phialemonium* antigens, *Phialophora* antigens, *Prototheca* antigens, *Pseudallescheria* antigens, *Pseudomicrodochium* antigens, *Pythium* antigens, *Rhinosporidium* antigens,

Rhizopus antigens, *Scolecobasidium* antigens, *Sporothrix* antigens, *Stemphylium* antigens, *Trichophyton* antigens, *Trichosporon* antigens, and *Xylohypha* antigens.

[0118] Examples of protozoan parasite antigens include, but are not limited to, *Babesia* antigens, *Balantidium* antigens, *Besnoitia* antigens, *Cryptosporidium* antigens, *Eimeri* antigens *a* antigens, *Encephalitozoon* antigens, *Entamoeba* antigens, *Giardia* antigens, *Hammondia* antigens, *Hepatozoon* antigens, *Isospora* antigens, *Leishmania* antigens, *Microsporidia* antigens, *Neospora* antigens, *Nosema* antigens, *Pentatrichomonas* antigens, *Plasmodium* antigens, e.g., *P. falciparum* circumsporozoite (PfCSP), sporozoite surface protein 2 (PfSSP2), carboxyl terminus of liver stage antigen 1 (PfLSA-1 c-term), and exported protein 1 (PfExp-1) antigens, *Pneumocystis* antigens, *Sarcocystis* antigens, *Schistosoma* antigens, *Theileria* antigens, *Toxoplasma* antigens, and *Trypanosoma* antigens. Examples of helminth parasite antigens include, but are not limited to, *Acanthocheilonema* antigens, *Aelurostrongylus* antigens, *Ancylostoma* antigens, *Angiostrongylus* antigens, *Ascaris* antigens, *Brugia* antigens, *Bunostomum* antigens, *Capillaria* antigens, *Chabertia* antigens, *Cooperia* antigens, *Crenosoma* antigens, *Dictyocaulus* antigens, *Diectophyme* antigens, *Dipetalonema* antigens, *Diphyllbothrium* antigens, *Diplydium* antigens, *Dirofilaria* antigens, *Dracunculus* antigens, *Enterobius* antigens, *Filaroides*,antigens *Haemonchus* antigens, *Lagochilascaris* antigens, *Loa* antigens, *Mansonella* antigens, *Muellerius* antigens, *Nanophyetus* antigens, *Necator* antigens, *Nematodirus* antigens, *Oesophagostomum* antigens, *Onchocerca* antigens, *Opisthorchis* antigens, *Ostertagia* antigens, *Parafilaria* antigens, *Paragonimus* antigens, *Parascaris* antigens, *Physaloptera* antigens, *Protostrongylus* antigens, *Setaria* antigens, *Spirocerca*,antigens *Spirometra* antigens, *Stephanofilaria* antigens, *Strongyloides* antigens, *Strongylus* antigens, *Thelazia* antigens, *Toxascaris* antigens, *Toxocara* antigens, *Trichinella* antigens, *Trichostrongylus* antigens, *Trichuris* antigens. *Uncinaria* antigens, and *Wuchereria* antigens.

[0119] In certain selection and screening schemes in which immunoglobulin molecules are expressed on the surface of host cells, the host cells of the present invention are "contacted" with antigen by a method which will allow an antigen,

which specifically recognizes a CDR of an immunoglobulin molecule expressed on the surface of the host cell, to bind to the CDR, thereby allowing the host cells which specifically bind the antigen to be distinguished from those host cells which do not bind the antigen. Any method which allows host cells expressing an antigen-specific antibody to interact with the antigen is included. For example, if the host cells are in suspension, and the antigen is attached to a solid substrate, cells which specifically bind to the antigen will be trapped on the solid substrate, allowing those cells which do not bind the antigen to be washed away, and the bound cells to be subsequently recovered. Alternatively, if the host cells are attached to a solid substrate, and by specifically binding antigen cells are caused to be released from the substrate (*e.g.*, by cell death), they can be recovered from the cell supernatant. Preferred methods by which to allow host cells of the invention to contact antigen, especially using libraries constructed in vaccinia virus vectors by trimolecular recombination, are disclosed herein.

[0120] In a preferred screening method for the detection of antigen-specific immunoglobulin molecules expressed on the surface of host cells, the host cells of the present invention are incubated with a selecting antigen that has been labeled directly with fluorescein-5-isothiocyanate (FITC) or indirectly with biotin then detected with FITC-labeled streptavidin. Other fluorescent probes can be employed which will be familiar to those practiced in the art. During the incubation period, the labeled selecting antigen binds the antigen-specific immunoglobulin molecules. Cells expressing an antibody receptor for a specific fluorescence tagged antigen can be selected by fluorescence activated cell sorting, thereby permitting the host cells which specifically bind the antigen to be distinguished from those host cells which do not bind the antigen. With the advent of cell sorters capable of sorting more than 1×10^8 cells per hour, it is feasible to screen large numbers of cells infected with recombinant vaccinia libraries of immunoglobulin genes to select the subset of cells that express specific antibody receptors to the selecting antigen.

[0121] After recovery of host cells which specifically bind antigen, polynucleotides of the first library are recovered from those host cells. By

"recovery" is meant a crude separation of a desired component from those components which are not desired. For example, host cells which bind antigen are "recovered" based on their detachment from a solid substrate, and polynucleotides of the first library are recovered from those cells by crude separation from other cellular components. It is to be noted that the term "recovery" does not imply any sort of purification or isolation away from viral and other components. Recovery of polynucleotides may be accomplished by any standard method known to those of ordinary skill in the art. In a preferred aspect, the polynucleotides are recovered by harvesting infectious virus particles, for example, particles of a vaccinia virus vector into which the first library has been constructed, which were contained in those host cells which bound antigen.

[0122] In certain screening schemes in which immunoglobulin molecules are fully secreted from the surface of host cells, the cell medium in which pools of host cells are cultured, *i.e.*, "conditioned medium," may be "contacted" with antigen by a method which will allow an antigen which specifically recognizes a CDR of an immunoglobulin molecule to bind to the CDR, and which further allows detection of the antigen-antibody interaction. Such methods include, but are not limited to, immunoblots, ELISA assays, RIA assays, RAST assays, and immunofluorescence assays. Alternatively, the conditioned medium is subjected to a functional assay for specific antibodies. Examples of such assays include, but are not limited to, virus neutralization assays (for antibodies directed to specific viruses), bacterial opsonization/phagocytosis assays (for antibodies directed to specific bacteria), antibody-dependent cellular cytotoxicity (ADCC) assays, assays to detect inhibition or facilitation of certain cellular functions, assays to detect IgE-mediated histamine release from mast cells, hemagglutination assays, and hemagglutination inhibition assays. Such assays will allow detection of antigen-specific antibodies with desired functional characteristics.

[0123] After the identification of conditioned medium pools containing immunoglobulin molecules which specifically bind antigen, or which have desired functional characteristics, further screening steps are carried out until host

cells which produce the desired immunoglobulin molecules are recovered, and then polynucleotides of the first library are recovered from those host cells.

[0124] As will be readily appreciated by those of ordinary skill in the art, identification of polynucleotides encoding immunoglobulin subunit polypeptides may require two or more rounds of selection as described above, and will necessarily require two or more rounds of screening as described above. A single round of selection may not necessarily result in isolation of a pure set of polynucleotides encoding the desired first immunoglobulin subunit polypeptides; the mixture obtained after a first round may be enriched for the desired polynucleotides but may also be contaminated with non-target insert sequences. Screening assays described herein identify pools containing the reactive host cells, and/or immunoglobulin molecules, but such pools will also contain non-reactive species. Therefore, the reactive pools are further fractionated and subjected to further rounds of screening. Thus, identification of polynucleotides encoding a first immunoglobulin subunit polypeptide which, in association with a second immunoglobulin subunit polypeptide, is capable of forming a desired immunoglobulin molecule, or antigen-specific fragment thereof, may require or benefit from several rounds of selection and/or screening, which thus increases the proportion of cells containing the desired polynucleotides. Accordingly, this embodiment further provides that the polynucleotides recovered after the first round be introduced into a second population of cells and be subjected to a second round of selection.

[0125] Accordingly, the first selection step, as described, may, or must be repeated one or more times, thereby enriching for the polynucleotides encoding the desired immunoglobulin subunit polypeptides. In order to repeat the first step of this embodiment, those polynucleotides, or pools of polynucleotides, recovered as described above are introduced into a population of host cells capable of expressing the immunoglobulin molecules encoded by the polynucleotides in the library. The host cells may be of the same type used in the first round of selection, or may be a different host cell, as long as they are capable of expressing the immunoglobulin molecules. The second library of

polynucleotides are also introduced into these host cells, and expression of immunoglobulin molecules, or antigen-specific fragments thereof, on the membrane surface of said host cells, or in the cell medium, is permitted. The cells or condition medium are similarly contacted with antigen, or the medium is tested in a functional assay, and polynucleotides of the first library are again recovered from those cells or pools of host cells which express an immunoglobulin molecule that specifically binds antigen, and/or has a desired functional characteristic. These steps may be repeated one or more times, resulting in enrichment for polynucleotides derived from the first library which encode an immunoglobulin subunit polypeptide which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, specifically binds the antigen and/or has a desired functional characteristic.

[0126] Following suitable enrichment for the desired polynucleotides from the first library as described above, those polynucleotides which have been recovered are "isolated," *i.e.*, they are substantially removed from their native environment and are largely separated from polynucleotides in the library which do not encode antigen-specific immunoglobulin subunit polypeptides. For example, cloned polynucleotides contained in a vector are considered isolated for the purposes of the present invention. It is understood that two or more different immunoglobulin subunit polypeptides which specifically bind the same antigen can be recovered by the methods described herein. Accordingly, a mixture of polynucleotides which encode polypeptides binding to the same antigen is also considered to be "isolated." Further examples of isolated polynucleotides include those maintained in heterologous host cells or purified (partially or substantially) DNA molecules in solution. However, a polynucleotide contained in a clone that is a member of a mixed library and that has not been isolated from other clones of the library, *e.g.*, by virtue of encoding an antigen-specific immunoglobulin subunit polypeptide, is not "isolated" for the purposes of this invention. For example, a polynucleotide contained in a virus vector is "isolated" after it has been recovered, and plaque purified, and a polynucleotide contained in a plasmid vector is isolated after it has been expanded from a single bacterial colony.

[0127] Given that an antigen may comprise two or more epitopes, and several different immunoglobulin molecules may bind to any given epitope, it is contemplated that several suitable polynucleotides, *e.g.*, two, three, four, five, ten, 100 or more polynucleotides, may be recovered from the first step of this embodiment, all of which may encode an immunoglobulin subunit polypeptide which, when combined with a suitable immunoglobulin subunit polypeptide encoded by a polynucleotide of the second library, will form an immunoglobulin molecule, or antigen binding fragment thereof, capable of specifically binding the antigen of interest. It is contemplated that each different polynucleotide recovered from the first library would be separately isolated. However, these polynucleotides may be isolated as a group of polynucleotides which encode polypeptides with the same antigen specificity, and these polynucleotides may be "isolated" together. Such mixtures of polynucleotides, whether separately isolated or collectively isolated, may be introduced into host cells in the second step, as explained below, either individually, or with two, three, four, five, ten, 100 or more of the polynucleotides pooled together.

[0128] Once one or more suitable polynucleotides from the first library are isolated, in the second step of this embodiment, one or more polynucleotides are identified in the second library which encode immunoglobulin subunit polypeptides which are capable of associating with the immunoglobulin subunit polypeptide(s) encoded by the polynucleotides isolated from the first library to form an immunoglobulin molecule, or antigen-binding fragment thereof, which specifically binds an antigen of interest, or has a desired functional characteristic.

[0129] Accordingly, the second step comprises introducing into a population of host cells capable of expressing an immunoglobulin molecule the second library of polynucleotides encoding a second immunoglobulin subunit polypeptide, introducing into the same population of host cells at least one of the polynucleotides isolated from the first library as described above, permitting expression of immunoglobulin molecules, or antigen-specific fragments thereof, on the surface of the host cells, or fully secreted into the cell medium, contacting those host cells, or conditioned medium in which the host cells were grown, with

the specific antigen of interest, or subjecting the conditioned medium to a functional assay, and recovering polynucleotides of the second library from those host cells which bind the antigen of interest, or those host cells which were grown in the conditioned medium which exhibits a desired reactivity. The second step is thus carried out very similarly to the first step, except that the second immunoglobulin subunit polypeptides encoded by the polynucleotides of the second library are combined in the host cells with just those polynucleotides isolated from the first library. As mentioned above, a single cloned polynucleotide isolated from the first library may be used, or alternatively a pool of several polynucleotides isolated from the first library may be introduced simultaneously. As with the first step described above, one or more rounds of enrichment are carried out, *i.e.*, either selection or screening of successively smaller pools, thereby enriching for polynucleotides of the second library which encode a second immunoglobulin subunit polypeptide which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, specifically binds the antigen of interest, or exhibits a desired functional characteristic. Also as with the first step, one or more desired polynucleotides from the second library are then isolated. If a pool of isolated polynucleotides is used in the earlier rounds of enrichment during the second step, preferred subsequent enrichment steps may utilize smaller pools of polynucleotides isolated from the first library, or even more preferably individual cloned polynucleotides isolated from the first library. For any individual polynucleotide isolated from the first library which is then used in the selection process for polynucleotides of the second library, it is possible that several, *i.e.* two, three, four, five, ten, 100, or more polynucleotides may be isolated from the second library which encode a second immunoglobulin subunit polypeptide capable of associating with a first immunoglobulin subunit polypeptide encoded by a polynucleotide isolated from the first library to form an immunoglobulin molecule, or antigen binding fragment thereof, which specifically binds the antigen of interest, or exhibits a desired functional characteristic.

- [0130] The selection/screening methods for libraries encoding single-chain fragments require only one library rather than first and second libraries, and only one selection/screening step is necessary. Similar to each of the two-steps for the immunoglobulins this one-step selection/screening method may also benefit from two or more rounds of enrichment.
- [0131] Vectors. In constructing antibody libraries in eukaryotic cells, any standard vector which allows expression in eukaryotic cells may be used. For example, the library could be constructed in a virus, plasmid, phage, or phagemid vector as long as the particular vector chosen comprises transcription and translation regulatory regions capable of functioning in eukaryotic cells. However, antibody libraries as described above are preferably constructed in eukaryotic virus vectors.
- [0132] Eukaryotic virus vectors may be of any type, *e.g.*, animal virus vectors or plant virus vectors. The naturally-occurring genome of the virus vector may be RNA, either positive strand, negative strand, or double stranded, or DNA, and the naturally-occurring genomes may be either circular or linear. Of the animal virus vectors, those that infect either invertebrates, *e.g.*, insects, protozoans, or helminth parasites; or vertebrates, *e.g.*, mammals, birds, fish, reptiles, and amphibians are included. The choice of virus vector is limited only by the maximum insert size, and the level of protein expression achieved. Suitable virus vectors are those that infect yeast and other fungal cells, insect cells, protozoan cells, plant cells, bird cells, fish cells, reptilian cells, amphibian cells, or mammalian cells, with mammalian virus vectors being particularly preferred. Any standard virus vector could be used in the present invention, including, but not limited to poxvirus vectors (*e.g.*, vaccinia virus), herpesvirus vectors (*e.g.*, herpes simplex virus), adenovirus vectors, baculovirus vectors, retrovirus vectors, picorna virus vectors (*e.g.*, poliovirus), alphavirus vectors (*e.g.*, sindbis virus), and enterovirus vectors (*e.g.*, mengovirus). DNA virus vectors, *e.g.*, poxvirus, herpes virus, baculovirus, and adenovirus are preferred. As described in more detail below, the poxviruses, particularly orthopoxviruses, and especially vaccinia virus, are particularly preferred. In a preferred embodiment, host cells are utilized

which are permissive for the production of infectious viral particles of whichever virus vector is chosen. Many standard virus vectors, such as vaccinia virus, have a very broad host range, thereby allowing the use of a large variety of host cells.

[0133] As mentioned *supra*, the first and second libraries of the invention may be constructed in the same vector, or may be constructed in different vectors. However, in preferred embodiments, the first and second libraries are prepared such that polynucleotides of the first library can be conveniently recovered, *e.g.*, separated, from the polynucleotides of the second library in the first step, and the polynucleotides of the second library can be conveniently recovered from the polynucleotides of the first library in the second step. For example, in the first step, if the first library is constructed in a virus vector, and the second library is constructed in a plasmid vector, the polynucleotides of the first library are easily recovered as infectious virus particles, while the polynucleotides of the second library are left behind with cellular debris. Similarly, in the second step, if the second library is constructed in a virus vector, while the polynucleotides of the first library isolated in the first step are introduced in a plasmid vector, infectious virus particles containing polynucleotides of the second library are easily recovered.

[0134] When the second library of polynucleotides, or the polynucleotides isolated from the first library are introduced into host cells in a plasmid vector, it is preferred that the immunoglobulin subunit polypeptides encoded by polynucleotides comprised in such plasmid vectors be operably associated with transcriptional regulatory regions which are driven by proteins encoded by virus vector which contains the other library. For example, if the first library is constructed in a poxvirus vector, and the second library is constructed in a plasmid vector, it is preferred that the polynucleotides encoding the second immunoglobulin subunit polypeptides constructed in the plasmid library be operably associated with a transcriptional control region, preferably a promoter, which functions in the cytoplasm of poxvirus-infected cells. Similarly in the second step, if it is desired to insert the polynucleotides isolated from the first library into a plasmid vector, and the second library is constructed in a poxvirus

vector, it is preferred that polynucleotides isolated from the first library and inserted into plasmids be operably associated with a transcriptional regulatory region, preferably a promoter, which functions in the cytoplasm of poxvirus-infected cells. Suitable and preferred examples of such transcriptional control regions are disclosed herein. In this way, the polynucleotides of the second library are only expressed in those cells which have also been infected by a poxvirus.

[0135] However, it is convenient to be able to maintain both the first and second libraries, as well as those polynucleotides isolated from the first library, in just a virus vector rather than having to maintain one or both of the libraries in two different vector systems. Accordingly, the present invention provides that samples of the first or second libraries, maintained in a virus vector, are inactivated such that the virus vector infects cells and the genome of virus vector is transcribed, but the vector is not replicated, *i.e.*, when the virus vector is introduced into cells, gene products carried on the virus genome, *e.g.*, immunoglobulin subunit polypeptides, are expressed, but infectious virus particles are not produced.

[0136] In a preferred aspect, inactivation of either the first or second library constructed in a eukaryotic virus vector is carried out by treating a sample of the library constructed in a virus vector with 4'-aminomethyl-trioxsalen (psoralen) and then exposing the virus vector to ultraviolet (UV) light. Psoralen and UV inactivation of viruses is well known to those of ordinary skill in the art. *See, e.g.*, Tsung, K., *et al.*, *J. Virol.* 70:165-171 (1996), which is incorporated herein by reference in its entirety.

[0137] Psoralen treatment typically comprises incubating a cell-free sample of the virus vector with a concentration of psoralen ranging from about 0.1 $\mu\text{g/ml}$ to about 20 $\mu\text{g/ml}$, preferably about 1 $\mu\text{g/ml}$ to about 17.5 $\mu\text{g/ml}$, about 2.5 $\mu\text{g/ml}$ to about 15 $\mu\text{g/ml}$, about 5 $\mu\text{g/ml}$ to about 12.5 $\mu\text{g/ml}$, about 7.5 $\mu\text{g/ml}$ to about 12.5 $\mu\text{g/ml}$, or about 9 $\mu\text{g/ml}$ to about 11 $\mu\text{g/ml}$. Accordingly, the concentration of psoralen may be about 0.1 $\mu\text{g/ml}$, 0.5 $\mu\text{g/ml}$, 1 $\mu\text{g/ml}$, 2 $\mu\text{g/ml}$, 3 $\mu\text{g/ml}$, 4 $\mu\text{g/ml}$, 5 $\mu\text{g/ml}$, 6 $\mu\text{g/ml}$, 7 $\mu\text{g/ml}$, 8 $\mu\text{g/ml}$, 9 $\mu\text{g/ml}$, 10 $\mu\text{g/ml}$, 11 $\mu\text{g/ml}$, 12 $\mu\text{g/ml}$,

13 $\mu\text{g/ml}$, 14 $\mu\text{g/ml}$, 15 $\mu\text{g/ml}$, 16 $\mu\text{g/ml}$, 17 $\mu\text{g/ml}$, 18 $\mu\text{g/ml}$, 19 $\mu\text{g/ml}$, or 20 $\mu\text{g/ml}$. Preferably, the concentration of psoralen is about 10 $\mu\text{g/ml}$. As used herein, the term "about" takes into account that measurements of time, chemical concentration, temperature, pH, and other factors typically measured in a laboratory or production facility are never exact, and may vary by a given amount based on the type of measurement and the instrumentation used to make the measurement.

[0138] The incubation with psoralen is typically carried out for a period of time prior to UV exposure. This time period preferably ranges from about one minute to about 20 minutes prior to the UV exposure. Preferably, the time period ranges from about 2 minutes to about 19 minutes, from about 3 minutes to about 18 minutes, from about 4 minutes to about 17 minutes, from about 5 minutes to about 16 minutes, from about 6 minutes to about 15 minutes, from about 7 minutes to about 14 minutes, from about 8 minutes to about 13 minutes, or from about 9 minutes to about 12 minutes. Accordingly, the incubation time may be about 1 minute, about 2 minutes, about three minutes, about 4 minutes, about 5 minutes, about 6 minutes, about 7 minutes, about 8 minutes, about 9 minutes, about 10 minutes, about 11 minutes, about 12 minutes, about 13 minutes, about 14 minutes, about 15 minutes, about 16 minutes, about 17 minutes, about 18 minutes, about 19 minutes, or about 20 minutes. More preferably, the incubation is carried out for 10 minutes prior to the UV exposure.

[0139] The psoralen-treated viruses are then exposed to UV light. The UV may be of any wavelength, but is preferably long-wave UV light, *e.g.*, about 365 nm. Exposure to UV is carried out for a time period ranging from about 0.1 minute to about 20 minutes. Preferably, the time period ranges from about 0.2 minute to about 19 minutes, from about 0.3 minute to about 18 minutes, from about 0.4 minute to about 17 minutes, from about 0.5 minute to about 16 minutes, from about 0.6 minute to about 15 minutes, from about 0.7 minute to about 14 minutes, from about 0.8 minute to about 13 minutes, from about 0.9 minute to about 12 minutes, from about 1 minute to about 11 minutes, from about 2 minutes to about 10 minutes, from about 2.5 minutes to about 9 minutes, from about 3 minutes to

about 8 minutes, from about 4 minutes to about 7 minutes, or from about 4.5 minutes to about 6 minutes. Accordingly, the incubation time may be about 0.1 minute, about 0.5 minute, about 1 minute, about 2 minutes, about three minutes, about 4 minutes, about 5 minutes, about 6 minutes, about 7 minutes, about 8 minutes, about 9 minutes, about 10 minutes, about 11 minutes, about 12 minutes, about 13 minutes, about 14 minutes, about 15 minutes, about 16 minutes, about 17 minutes, about 18 minutes, about 19 minutes, or about 20 minutes. More preferably, the virus vector is exposed to UV light for a period of about 5 minutes.

[0140] The ability to assemble and express immunoglobulin molecules or antigen-specific fragments thereof in eukaryotic cells from two libraries of polynucleotides encoding immunoglobulin subunit polypeptides provides a significant improvement over the methods of producing single-chain antibodies in bacterial systems, in that the two-step selection process can be the basis for selection of immunoglobulin molecules or antigen-specific fragments thereof with a variety of specificities.

[0141] Examples of specific embodiments which further illustrate, but do not limit this embodiment, are provided in the Examples below. As described in detail, *supra*, selection of specific immunoglobulin subunit polypeptides, *e.g.*, immunoglobulin heavy and light chains, is accomplished in two phases. First, a library of diverse heavy chains from immunoglobulin producing cells of either naïve or immunized donors is constructed in a eukaryotic virus vector, for example, a poxvirus vector, and a similarly diverse library of immunoglobulin light chains is constructed either in a plasmid vector, in which expression of the recombinant gene is regulated by a virus promoter, or in a eukaryotic virus vector which has been inactivated, *e.g.*, through psoralen and UV treatment. Host cells capable of expressing immunoglobulin molecules, or antigen-specific fragments thereof, are infected with virus vector encoding the heavy chain library at a multiplicity of infection of about 1 (MOI=1). "Multiplicity of infection" refers to the average number of virus particles available to infect each host cell. For example, if an MOI of 1, *i.e.*, an infection where, on average, each cell is infected

by one virus particle, is desired, the number of infectious virus particles to be used in the infection is adjusted to be equal to the number of cells to be infected.

[0142] According to this strategy, host cells are either transfected with the light chain plasmid library, or infected with the inactivated light chain virus library under conditions which allow, on average, 10 or more separate polynucleotides encoding light chain polypeptides to be taken up and expressed in each cell. Under these conditions, a single host cell can express multiple immunoglobulin molecules, or fragments thereof, with different light chains associated with the same heavy chains in characteristic H₂L₂ structures in each host cell.

[0143] It will be appreciated by those of ordinary skill in the art that controlling the number of plasmids taken up by a cell is difficult, because successful transfection depends on inducing a competent state in cells which may not be uniform and could lead to taking up variable amounts of DNA. Accordingly, in those embodiments where it is desired to carefully control the number of polynucleotides from the second library which are introduced into each infected host cell, the use of an inactivated virus vector is preferred, because the multiplicity of infection of viruses is more easily controlled.

[0144] The expression of multiple light chains in a single host cell, associated with a single heavy chain, has the effect of reducing the avidity of specific antigen immunoglobulin, but may be beneficial for selection of relatively high affinity binding sites. As used herein, the term "affinity" refers to a measure of the strength of the binding of an individual epitope with the CDR of an immunoglobulin molecule. *See, e.g.*, Harlow at pages 27-28. As used herein, the term "avidity" refers to the overall stability of the complex between a population of immunoglobulins and an antigen, that is, the functional combining strength of an immunoglobulin mixture with the antigen. *See, e.g.*, Harlow at pages 29-34. Avidity is related to both the affinity of individual immunoglobulin molecules in the population with specific epitopes, and also the valencies of the immunoglobulins and the antigen. For example, the interaction between a bivalent monoclonal antibody and an antigen with a highly repeating epitope structure, such as a polymer, would be one of high avidity. As will be appreciated

by those of ordinary skill in the art, if a host cell expresses immunoglobulin molecules on its surface, each comprising a given heavy chain, but where different immunoglobulin molecules on the surface comprise different light chains, the "avidity" of that host cell for a given antigen will be reduced. However, the possibility of recovering a group of immunoglobulin molecules which are related in that they comprise a common heavy chain, but which, through association with different light chains, react with a particular antigen with a spectrum of affinities, is increased. Accordingly, by adjusting the number of different light chains, or fragments thereof, which are allowed to associate with a certain number of heavy chains, or fragments thereof in a given host cell, the present invention provides a method to select for and enrich for immunoglobulin molecules, or antigen-specific fragments thereof, with varied affinity levels.

[0145] In utilizing this strategy in the first step of the method for selecting immunoglobulin molecules, or antigen-specific fragments thereof as described above, the first library is preferably constructed in a eukaryotic virus vector, and the host cells are infected with the first library at an MOI ranging from about 1 to about 10, preferably about 1, while the second library is introduced under conditions which allow up to 20 polynucleotides of said second library to be taken up by each infected host cell. For example, if the second library is constructed in an inactivated virus vector, the host cells are infected with the second library at an MOI ranging from about 1 to about 20, although MOIs higher or lower than this range may be desirable depending on the virus vector used and the characteristics of the immunoglobulin molecules desired. If the second library is constructed in a plasmid vector, transfection conditions are adjusted to allow anywhere from 0 plasmids to about 20 plasmids to enter each host cell. Selection for lower or higher affinity responses to antigen is controlled by increasing or decreasing the average number of polynucleotides of the second library allowed to enter each infected cell.

[0146] More preferably, where the first library is constructed in a virus vector, host cells are infected with the first library at an MOI ranging from about 1-9, about 1-8, about 1-7, about 1-6, about 1-5, about 1-4, or about 1-2. In other

words, host cells are infected with the first library at an MOI of about 10, about 9, about 8, about 7, about 6, about 5, about 4, about 3, about 2, or about 1. Most preferably, host cells are infected with the first library at an MOI of about 1.

[0147] Where the second library is constructed in a plasmid vector, the plasmid vector is more preferably introduced into host cells under conditions which allow up to about 19, about 18, about 17, about 16, about 15, about 14, about 13, about 12, about 10, about 9, about 8, about 7, about 6, about 5, about 4, about 3 about 2, or about 1 polynucleotide(s) of the second library to be taken up by each infected host cell. Most preferably, where the second library is constructed in a plasmid vector, the plasmid vector is introduced into host cells under conditions which allow up to about 10 polynucleotides of the second library to be taken up by each infected host cell.

[0148] Similarly, where the second library is constructed in an inactivated virus vector, it is more preferred to introduce the second library into host cells at an MOI ranging from about 1-19, about 2-18, about 3-17, about 4-16, about 5-15, about 6-14, about 7 -13, about 8-12, or about 9-11. In other words, host cells are infected with the second library at an MOI of about 20, about 19, about 18, about 17, about 16, about 15, about 14, about 13, about 12, about 11, about 10, about 9, about 8, about 7, about 6, about 5, about 4, about 3, about 2, or about 1. In a most preferred aspect, host cells are infected with the second library at an MOI of about 10. As will be understood by those of ordinary skill in the art, the titer, and thus the "MOI" of an inactivated virus cannot be directly measured, however, the titer may be inferred from the titer of the starting infectious virus stock which was subsequently inactivated.

[0149] In a most preferred aspect, the first library is constructed in a virus vector and the second library is constructed in a virus vector which has been inactivated, the host cells are infected with said first library at an MOI of about 1, and the host cells are infected with the second library at an MOI of about 10.

[0150] In the present invention, a preferred virus vector is derived from a poxvirus, *e.g.*, vaccinia virus. If the first library encoding the first immunoglobulin subunit polypeptide is constructed in a poxvirus vector and the

expression of second immunoglobulin subunit polypeptides, encoded by the second library constructed either in a plasmid vector or an inactivated virus vector, are regulated by a poxvirus promoter, high levels of the second immunoglobulin subunit polypeptide are expressed in the cytoplasm of the poxvirus infected cells without a requirement for nuclear integration.

[0151] In the second step of the immunoglobulin selection as described above, the second library is preferably constructed in an infectious eukaryotic virus vector, and the host cells are infected with the second library at an MOI ranging from about 1 to about 10. More preferably, where the second library is constructed in a virus vector, host cells are infected with the second library at an MOI ranging from about 1-9, about 1-8, about 1-7, about 1-6, about 1-5, about 1-4, or about 1-2. In other words, host cells are infected with the second library at an MOI of about 10, about 9, about 8, about 7, about 6, about 5, about 4, about 3, about 2, or about 1. Most preferably, host cells are infected with the second library at an MOI of about 1.

[0152] In the second step of the immunoglobulin selection, polynucleotides from the first library have been isolated. In certain embodiments, a single first library polynucleotide, *i.e.*, a clone, is introduced into the host cells used to isolate polynucleotides from the second library. In this situation, the polynucleotides isolated from the first library are introduced into host cells under conditions which allow at least about 1 polynucleotide per host cell. However, since all the polynucleotides being introduced from the first library will be the same, *i.e.*, copies of a cloned polynucleotide, the number of polynucleotides introduced into any given host cell is less important. For example, if a cloned polynucleotide isolated from the first library is contained in an inactivated virus vector, that vector would be introduced at an MOI of about 1, but an MOI greater than 1 would be acceptable. Similarly, if a cloned polynucleotide isolated from the first library is introduced in a plasmid vector, the number of plasmids which are introduced into any given host cell is of little importance, rather, transfection conditions should be adjusted to insure that at least one polynucleotide is introduced into each host cell. An alternative embodiment may be utilized if, for

example, several different polynucleotides were isolated from the first library. In this embodiment, pools of two or more different polynucleotides isolated from the first library may be advantageously introduced into host cells infected with the second library of polynucleotides. In this situation, if the polynucleotides isolated from the first library are contained in an inactivated virus vector, an MOI of inactivated virus particles of greater than about 1, *e.g.*, about 2, about 3, about 4, about 5, or more may be preferred, or if the polynucleotides isolated from the first library are contained in a plasmid vector, conditions which allow at least about 2, 3, 4, 5, or more polynucleotides to enter each cell, may be preferred.

[0153] Poxvirus Vectors. As noted above, a preferred virus vector for use in the present invention is a poxvirus vector. "Poxvirus" includes any member of the family Poxviridae, including the subfamililes Chordopoxviridae (vertebrate poxviruses) and Entomopoxviridae (insect poxviruses). *See*, for example, B. Moss in: *Virology, 2d Edition*, B.N. Fields, D.M. Knipe *et al.*, Eds., Raven Press, p. 2080 (1990). The chordopoxviruses comprise, *inter alia*, the following genera: Orthopoxvirus (*e.g.*, vaccinia, variola virus, raccoon poxvirus); Avipoxvirus (*e.g.*, fowlpox); Capripoxvirus (*e.g.*, sheeppox) Leporipoxvirus (*e.g.*, rabbit (Shope) fibroma, and myxoma); and Suipoxvirus (*e.g.*, swinepox). The entomopoxviruses comprise three genera: A, B and C. In the present invention, orthopoxviruses are preferred. Vaccinia virus is the prototype orthopoxvirus, and has been developed and is well-characterized as a vector for the expression of heterologous proteins. In the present invention, vaccinia virus vectors, particularly those that have been developed to perform trimolecular recombination, are preferred. However, other orthopoxviruses, in particular, raccoon poxvirus have also been developed as vectors and in some applications, have superior qualities.

[0154] Poxviruses are distinguished by their large size and complexity, and contain similarly large and complex genomes. Notably, poxviruses replication takes place entirely within the cytoplasm of a host cell. The central portions of poxvirus genomes are similar, while the terminal portions of the virus genomes are characterized by more variability. Accordingly, it is thought that the central portion of poxvirus genomes carry genes responsible for essential functions

common to all poxviruses, such as replication. By contrast, the terminal portions of poxvirus genomes appear responsible for characteristics such as pathogenicity and host range, which vary among the different poxviruses, and may be more likely to be non-essential for virus replication in tissue culture. It follows that if a poxvirus genome is to be modified by the rearrangement or removal of DNA fragments or the introduction of exogenous DNA fragments, the portion of the naturally-occurring DNA which is rearranged, removed, or disrupted by the introduction of exogenous DNA is preferably in the more distal regions thought to be non-essential for replication of the virus and production of infectious virions in tissue culture.

[0155] The naturally-occurring vaccinia virus genome is a cross-linked, double stranded linear DNA molecule, of about 186,000 base pairs (bp), which is characterized by inverted terminal repeats. The genome of vaccinia virus has been completely sequenced, but the functions of most gene products remain unknown. Goebel, S.J., *et al.*, *Virology* 179:247-266, 517-563 (1990); Johnson, G.P., *et al.*, *Virology* 196:381-401. A variety of non-essential regions have been identified in the vaccinia virus genome. *See, e.g.*, Perkus, M.E., *et al.*, *Virology* 152:285-97 (1986); and Kotwal, G.J. and Moss B., *Virology* 167:524-37.

[0156] In those embodiments where poxvirus vectors, in particular vaccinia virus vectors, are used to express immunoglobulin subunit polypeptides, any suitable poxvirus vector may be used. It is preferred that the libraries of immunoglobulin subunit polypeptides be carried in a region of the vector which is non-essential for growth and replication of the vector so that infectious viruses are produced. Although a variety of non-essential regions of the vaccinia virus genome have been characterized, the most widely used locus for insertion of foreign genes is the thymidine kinase locus, located in the HindIII J fragment in the genome. In certain preferred vaccinia virus vectors, the tk locus has been engineered to contain one or two unique restriction enzyme sites, allowing for convenient use of the trimolecular recombination method of library generation. *See infra*, and also Zauderer, PCT Publication No. WO 00/028016.

- [0157] Libraries of polynucleotides encoding immunoglobulin subunit polypeptides are inserted into poxvirus vectors, particularly vaccinia virus vectors, under operable association with a transcriptional control region which functions in the cytoplasm of a poxvirus-infected cell.
- [0158] Poxvirus transcriptional control regions comprise a promoter and a transcription termination signal. Gene expression in poxviruses is temporally regulated, and promoters for early, intermediate, and late genes possess varying structures. Certain poxvirus genes are expressed constitutively, and promoters for these "early-late" genes bear hybrid structures. Synthetic early-late promoters have also been developed. See Hammond J.M., *et al.*, *J. Virol. Methods* 66:135-8 (1997); Chakrabarti S., *et al.*, *Biotechniques* 23:1094-7 (1997). In the present invention, any poxvirus promoter may be used, but use of early, late, or constitutive promoters may be desirable based on the host cell and/or selection scheme chosen. Typically, the use of constitutive promoters is preferred.
- [0159] Examples of early promoters include the 7.5-kD promoter (also a late promoter), the DNA pol promoter, the tk promoter, the RNA pol promoter, the 19-kD promoter, the 22-kD promoter, the 42-kD promoter, the 37-kD promoter, the 87-kD promoter, the H3' promoter, the H6 promoter, the D1 promoter, the D4 promoter, the D5 promoter, the D9 promoter, the D12 promoter, the I3 promoter, the M1 promoter, and the N2 promoter. See, *e.g.*, Moss, B., "Poxviridae and their Replication" IN *Virology, 2d Edition*, B.N. Fields, D.M. Knipe *et al.*, Eds., Raven Press, p. 2088 (1990). Early genes transcribed in vaccinia virus and other poxviruses recognize the transcription termination signal TTTTTNT, where N can be any nucleotide. Transcription normally terminates approximately 50 bp upstream of this signal. Accordingly, if heterologous genes are to be expressed from poxvirus early promoters, care must be taken to eliminate occurrences of this signal in the coding regions for those genes. See, *e.g.*, Earl, P.L., *et al.*, *J. Virol.* 64:2448-51 (1990).
- [0160] Example of late promoters include the 7.5-kD promoter, the MIL promoter, the 37-kD promoter, the 11-kD promoter, the 11L promoter, the 12L promoter, the 13L promoter, the 15L promoter, the 17L promoter, the 28-kD

promoter, the H1L promoter, the H3L promoter, the H5L promoter, the H6L promoter, the H8L promoter, the D11L promoter, the D12L promoter, the D13L promoter, the A1L promoter, the A2L promoter, the A3L promoter, and the P4b promoter. *See, e.g.*, Moss, B., "Poxviridae and their Replication" IN *Virology*, 2d Edition, B.N. Fields, D.M. Knipe *et al.*, Eds., Raven Press, p. 2090 (1990). The late promoters apparently do not recognize the transcription termination signal recognized by early promoters.

[0161] Preferred constitutive promoters for use in the present invention include the synthetic early-late promoters described by Hammond and Chakrabarti, the MH-5 early-late promoter, and the 7.5-kD or "p7.5" promoter. Examples utilizing these promoters are disclosed herein.

[0162] As will be discussed in more detail below, certain selection and screening methods based on host cell death require that the mechanisms leading to cell death occur prior to any cytopathic effect (CPE) caused by virus infection. The kinetics of the onset of CPE in virus-infected cells is dependent on the virus used, the multiplicity of infection, and the type of host cell. For example, in many tissue culture lines infected with vaccinia virus at an MOI of about 1, CPE is not significant until well after 48 to 72 hours post-infection. This allows a 2 to 3 day time frame for high level expression of immunoglobulin molecules, and antigen-based selection independent of CPE caused by the vector. However, this time frame may not be sufficient for certain selection methods, especially where higher MOIs are used, and further, the time before the onset of CPE may be shorter in a desired cell line. There is, therefore, a need for virus vectors, particularly poxvirus vectors such as vaccinia virus, with attenuated cytopathic effects so that, wherever necessary, the time frame of selection can be extended.

[0163] For example, certain attenuations are achieved through genetic mutation. These may be fully defective mutants, *i.e.*, the production of infectious virus particles requires helper virus, or they may be conditional mutants, *e.g.*, temperature sensitive mutants. Conditional mutants are particularly preferred, in that the virus-infected host cells can be maintained in a non-permissive environment, *e.g.*, at a non-permissive temperature, during the period where host

gene expression is required, and then shifted to a permissive environment, *e.g.*, a permissive temperature, to allow virus particles to be produced. Alternatively, a fully infectious virus may be "attenuated" by chemical inhibitors which reversibly block virus replication at defined points in the infection cycle. Chemical inhibitors include, but are not limited to hydroxyurea and 5-fluorodeoxyuridine. Virus-infected host cells are maintained in the chemical inhibitor during the period where host gene expression is required, and then the chemical inhibitor is removed to allow virus particles to be produced.

[0164] A number of attenuated poxviruses, in particular vaccinia viruses, have been developed. For example, modified vaccinia Ankara (MVA) is a highly attenuated strain of vaccinia virus that was derived during over 570 passages in primary chick embryo fibroblasts (Mayr, A. *et al.*, *Infection* 3:6-14 (1975)). The recovered virus deleted approximately 15% of the wild type vaccinia DNA which profoundly affects the host range restriction of the virus. MVA cannot replicate or replicates very inefficiently in most mammalian cell lines. A unique feature of the host range restriction is that the block in non-permissive cells occurs at a relatively late stage of the replication cycle. Expression of viral late genes is relatively unimpaired but virion morphogenesis is interrupted (Suter, G. and Moss, B., *Proc Natl Acad Sci USA* 89:10847-51 (1992); Carroll, M.W. and Moss, B., *Virology* 238:198-211 (1997)). The high levels of viral protein synthesis even in non-permissive host cells make MVA an especially safe and efficient expression vector. However, because MVA cannot complete the infectious cycle in most mammalian cells, in order to recover infectious virus for multiple cycles of selection it will be necessary to complement the MVA deficiency by coinfection or superinfection with a helper virus that is itself deficient and that can be subsequently separated from infectious MVA recombinants by differential expansion at low MOI in MVA permissive host cells.

[0165] Poxvirus infection can have a dramatic inhibitory effect on host cell protein and RNA synthesis. These effects on host gene expression could, under some conditions, interfere with the selection of specific poxvirus recombinants that have a defined physiological effect on the host cell. Some strains of vaccinia

virus that are deficient in an essential early gene have been shown to have greatly reduced inhibitory effects on host cell protein synthesis. Attenuated poxviruses which lack defined essential early genes have also been described. *See, e.g.*, U.S. Patent Nos. 5,766,882, and 5,770,212, by Falkner, *et al.* Examples of essential early genes which may be rendered defective include, but are not limited to the vaccinia virus 17L, F18R, D13L, D6R, A8L, J1R, E7L, F11L, E4L, I1L, J3R, J4R, H7R, and A6R genes. A preferred essential early gene to render defective is the D4R gene, which encodes a uracil DNA glycosylase enzyme. Vaccinia viruses defective in defined essential genes are easily propagated in complementing cell lines which provides the essential gene product.

[0166] As used herein, the term "complementation" refers to a restoration of a lost function in trans by another source, such as a host cell, transgenic animal or helper virus. The loss of function is caused by loss by the defective virus of the gene product responsible for the function. Thus, a defective poxvirus is a non-viable form of a parental poxvirus, and is a form that can become viable in the presence of complementation. The host cell, transgenic animal or helper virus contains the sequence encoding the lost gene product, or "complementation element." The complementation element should be expressible and stably integrated in the host cell, transgenic animal or helper virus, and preferably would be subject to little or no risk for recombination with the genome of the defective poxvirus.

[0167] Viruses produced in the complementing cell line are capable of infecting non-complementing cells, and further are capable of high-level expression of early gene products. However, in the absence of the essential gene product, host shut-off, DNA replication, packaging, and production of infectious virus particles does not take place.

[0168] In particularly preferred embodiments described herein, selection of desired target gene products expressed in a complex library constructed in vaccinia virus is accomplished through coupling induction of expression of the complementation element to expression of the desired target gene product. Since the complementation element is only expressed in those host cells expressing the

desired gene product, only those host cells will produce infectious virus which is easily recovered.

[0169] The preferred embodiments relating to vaccinia virus may be modified in ways apparent to one of ordinary skill in the art for use with any poxvirus vector. In the direct selection method, vectors other than poxvirus or vaccinia virus may be used.

[0170] The Tri-Molecular Recombination Method. Traditionally, poxvirus vectors such as vaccinia virus have not been used to identify previously unknown genes of interest from a complex libraries because a high efficiency, high titer-producing method of constructing and screening libraries did not exist for vaccinia. The standard methods of heterologous protein expression in vaccinia virus involve *in vivo* homologous recombination and *in vitro* direct ligation. Using homologous recombination, the efficiency of recombinant virus production is in the range of approximately 0.1% or less. Although efficiency of recombinant virus production using direct ligation is higher, the resulting titer is relatively low. Thus, the use of vaccinia virus vector has been limited to the cloning of previously isolated DNA for the purposes of protein expression and vaccine development.

[0171] Tri-molecular recombination, as disclosed in Zauderer, PCT Publication No. WO 00/028016, is a novel, high efficiency, high titer-producing method for cloning in vaccinia virus. Using the tri-molecular recombination method, the present inventor has achieved generation of recombinant viruses at efficiencies of at least 90%, and titers at least at least 2 orders of magnitude higher than those obtained by direct ligation.

[0172] Thus, in a preferred embodiment, libraries of polynucleotides capable of expressing immunoglobulin subunit polypeptides are constructed in poxvirus vectors, preferably vaccinia virus vectors, by tri-molecular recombination.

[0173] By "tri-molecular recombination" or a "tri-molecular recombination method" is meant a method of producing a virus genome, preferably a poxvirus genome, and even more preferably a vaccinia virus genome comprising a

heterologous insert DNA, by introducing two nonhomologous fragments of a virus genome and a transfer vector or transfer DNA containing insert DNA into a recipient cell, and allowing the three DNA molecules to recombine *in vivo*. As a result of the recombination, a viable virus genome molecule is produced which comprises each of the two genome fragments and the insert DNA. Thus, the trimolecular recombination method as applied to the present invention comprises:

- (a) cleaving an isolated virus genome, preferably a DNA virus genome, more preferably a linear DNA virus genome, and even more preferably a poxvirus or vaccinia virus genome, to produce a first viral fragment and a second viral fragment, where the first viral fragment is nonhomologous with the second viral fragment;
- (b) providing a population of transfer plasmids comprising polynucleotides which encode immunoglobulin subunit polypeptides, *e.g.*, immunoglobulin light chains, immunoglobulin heavy chains, or antigen-specific fragments of either, through operable association with a transcription control region, flanked by a 5' flanking region and a 3' flanking region, wherein the 5' flanking region is homologous to said the viral fragment described in (a), and the 3' flanking region is homologous to said second viral fragment described in (a); and where the transfer plasmids are capable of homologous recombination with the first and second viral fragments such that a viable virus genome is formed;
- (c) introducing the transfer plasmids described in (b) and the first and second viral fragments described in (a) into a host cell under conditions where a transfer plasmid and the two viral fragments undergo *in vivo* homologous recombination, *i.e.*, trimolecular recombination, thereby producing a viable modified virus genome comprising a polynucleotide which encodes an immunoglobulin subunit polypeptide; and
- (d) recovering modified virus genomes produced by this technique. Preferably, the recovered modified virus genome is packaged in an infectious viral particle.

[0174] By "recombination efficiency" or "efficiency of recombinant virus production" is meant the ratio of recombinant virus to total virus produced during the generation of virus libraries of the present invention. As shown in Example 5, the efficiency may be calculated by dividing the titer of recombinant virus by

the titer of total virus and multiplying by 100%. For example, the titer is determined by plaque assay of crude virus stock on appropriate cells either with selection (*e.g.*, for recombinant virus) or without selection (*e.g.*, for recombinant virus plus wild type virus). Methods of selection, particularly if heterologous polynucleotides are inserted into the viral thymidine kinase (tk) locus, are well-known in the art and include resistance to bromdeoxyuridine (BDUR) or other nucleotide analogs due to disruption of the tk gene. Examples of selection methods are described herein.

[0175] By "high efficiency recombination" is meant a recombination efficiency of at least 1%, and more preferably a recombination efficiency of at least about 2%, 2.5%, 3%, 3.5%, 4%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 75%, 80%, 85%, 90%, 95%, or 99%.

[0176] A number of selection systems may be used, including but not limited to the thymidine kinase such as herpes simplex virus thymidine kinase (Wigler, *et al.*, 1977, *Cell* 11:223), hypoxanthine-guanine phosphoribosyltransferase (Szybalska & Szybalski, 1962, *Proc. Natl. Acad. Sci. USA* 48:2026), and adenine phosphoribosyltransferase (Lowy, *et al.*, 1980, *Cell* 22:817) genes which can be employed in tk⁻, hgp^rt⁻ or ap^rt⁻ cells, respectively. Also, antimetabolite resistance can be used as the basis of selection for the following genes: dhfr, which confers resistance to methotrexate (Wigler, *et al.*, 1980, *Proc. Natl. Acad. Sci. USA* 77:3567; O'Hare, *et al.*, 1981, *Proc. Natl. Acad. Sci. USA* 78:1527); gpt, which confers resistance to mycophenolic acid (Mulligan & Berg, 1981, *Proc. Natl. Acad. Sci. USA* 78:2072); neo, which confers resistance to the aminoglycoside G-418 (Colberre-Garapin, *et al.*, 1981, *J. Mol. Biol.* 150:1); and hyg^r, which confers resistance to hygromycin (Santerre, *et al.*, 1984, *Gene* 30:147).

[0177] Together, the first and second viral fragments or "arms" of the virus genome, as described above, preferably contain all the genes necessary for viral replication and for production of infectious viral particles. Examples of suitable arms and methods for their production using vaccinia virus vectors are disclosed herein. *See also* Falkner *et al.*, U.S. Pat. No. 5,770,212 for guidance concerning essential regions for vaccinia replication.

[0178] However, naked poxvirus genomic DNAs such as vaccinia virus genomes cannot produce infectious progeny without virus-encoded protein protein(s)/function(s) associated with the incoming viral particle. The required virus-encoded functions, include an RNA polymerase that recognizes the transfected vaccinia DNA as a template, initiates transcription and, ultimately, replication of the transfected DNA. *See* Dorner, *et al.* U.S. Pat. No. 5,445,953.

[0179] Thus, to produce infectious progeny virus by trimolecular recombination using a poxvirus such as vaccinia virus, the recipient cell preferably contains packaging function. The packaging function may be provided by helper virus, *i.e.*, a virus that, together with the transfected naked genomic DNA, provides appropriate proteins and factors necessary for replication and assembly of progeny virus.

[0180] The helper virus may be a closely related virus, for instance, a poxvirus of the same poxvirus subfamily as vaccinia, whether from the same or a different genus. In such a case it is advantageous to select a helper virus which provides an RNA polymerase that recognizes the transfected DNA as a template and thereby serves to initiate transcription and, ultimately, replication of the transfected DNA. If a closely related virus is used as a helper virus, it is advantageous that it be attenuated such that formation of infectious virus will be impaired. For example, a temperature sensitive helper virus may be used at the non-permissive temperature. Preferably, a heterologous helper virus is used. Examples include, but are not limited to an avipox virus such as fowlpox virus, or an ectromelia virus (mouse pox) virus. In particular, avipoxviruses are preferred, in that they provide the necessary helper functions, but do not replicate, or produce infectious virions in mammalian cells (Scheifflinger, *et al.*, *Proc. Natl. Acad. Sci. USA* 89:9977-9981 (1992)). Use of heterologous viruses minimizes recombination events between the helper virus genome and the transfected genome which take place when homologous sequences of closely related viruses are present in one cell. *See* Fenner & Comben, *Virology* 5:530 (1958); Fenner, *Virology* 8:499 (1959).

[0181] Alternatively, the necessary helper functions in the recipient cell is supplied by a genetic element other than a helper virus. For example, a host cell can be transformed to produce the helper functions constitutively, or the host cell can be transiently transfected with a plasmid expressing the helper functions, infected with a retrovirus expressing the helper functions, or provided with any other expression vector suitable for expressing the required helper virus function. See Dorner, *et al.* U.S. Pat. No. 5,445,953.

[0182] According to the trimolecular recombination method, the first and second viral genomic fragments are unable to ligate or recombine with each other, *i.e.*, they do not contain compatible cohesive ends or homologous regions, or alternatively, cohesive ends have been treated with a dephosphorylating enzyme. In a preferred embodiment, a virus genome comprises a first recognition site for a first restriction endonuclease and a second recognition site for a second restriction endonuclease, and the first and second viral fragments are produced by digesting the viral genome with the appropriate restriction endonucleases to produce the viral "arms," and the first and second viral fragments are isolated by standard methods. Ideally, the first and second restriction endonuclease recognition sites are unique in the viral genome, or alternatively, cleavage with the two restriction endonucleases results in viral "arms" which include the genes for all essential functions, *i.e.*, where the first and second recognition sites are physically arranged in the viral genome such that the region extending between the first and second viral fragments is not essential for virus infectivity.

[0183] In a preferred embodiment where a vaccinia virus vector is used in the trimolecular recombination method, a vaccinia virus vector comprising a virus genome with two unique restriction sites within the tk gene is used. In certain preferred vaccinia virus genomes, the first restriction enzyme is NotI, having the recognition site GCGGCCGC in the tk gene, and the second restriction enzyme is ApaI, having the recognition site GGGCCC in the tk gene. Even more preferred are vaccinia virus vectors comprising a v7.5/tk virus genome or a vEL/tk virus genome.

[0184] According to this embodiment, a transfer plasmid with flanking regions capable of homologous recombination with the region of the vaccinia virus genome containing the thymidine kinase gene is used. A fragment of the vaccinia virus genome comprising the HindIII-J fragment, which contains the tk gene, is conveniently used.

[0185] Where the virus vector is a poxvirus, the insert polynucleotides are preferably operably associated with poxvirus expression control sequences, more preferably, strong constitutive poxvirus promoters such as p7.5 or a synthetic early/late promoter.

[0186] Accordingly, a transfer plasmid of the present invention comprises a polynucleotide encoding an immunoglobulin subunit polypeptide, *e.g.*, an heavy chain, and immunoglobulin light chain, or an antigen-specific fragment of a heavy chain or a light chain, through operable association with a vaccinia virus p7.5 promoter, or a synthetic early/late promoter.

[0187] A preferred transfer plasmid of the present invention which comprises a polynucleotide encoding an immunoglobulin heavy chain polypeptide through operable association with a vaccinia virus p7.5 promoter is pVHE, which comprises the sequence:

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GGCCAAAATTTGAAAACTAGATCTATTTATTTGCACGCGGCCGCAAACCATGGGATGGAGCTG
TATCATCTCTTCTTGGTAGCAACAGCTACAGGCGCGCATATGGTCACCGTCTCCTCAGGGAG
TGCATCCGCCCAACCCTTTTCCCCCTCGTCTCCTGTGAGAATTCCCCGTCGGATACGAGCAG
CGTGGCCGTTGGCTGCCCTCGCACAGGACTTCCTTCCCGACTCCATCACTTTCTCCTGGAAATA
CAAGAACAACCTCTGACATCAGCAGCACCCGGGGCTTCCCATCAGTCCTGAGAGGGGGCAAGTA
CGCAGCCACCTCACAGGTGCTGCTGCCCTTCCAAGGACGTCATGCAGGGCACAGACGAACACGT
GGTGTGCAAAGTCCAGCACCCCAACGGCAACAAGAAAAGAACGTGCCTCTTCCAGTGATTGC
TGAGCTGCCCTCCCAAAGTGAGCGTCTTCGTCCCACCCCGCGACGGCTTCTTCGGCAACCCCCG
CAGCAAGTCCAAGCTCATCTGCCAGGCCACGGGTTTCAGTCCCCGGCAGATTCAGGTGTCTCTG
GCTGCGCGAGGGGAAGCAGGTGGGGTCTGGCGTCAACACGGACCGAGGTGCAGGCTGAGGCCAA
AGAGTCTGGGCCCACGACCTACAAGGTGACTAGCACACTGACCATCAAAGAGAGCGACTGGCT
CAGCCAGAGCATGTTACCTGCCGCGTGGATCACAGGGGCTGACCTTCCAGCAGAATGCGTC
CTCCATGTGTGTCCCCGATCAAGACACAGCCATCCGGGTCTTCGCCATCCCCCATCCTTTGC
CAGCATCTTCTTACCAAGTCCACCAAGTTGACCTGCCCTGGTTCACAGACCTGACCACCTATGA
CAGCGTGACCATCTCCTGGACCCGCCAGAATGGCGAAGCTGTGAAAACCCACACCAACATCTC
CGAGAGCCACCCCAATGCCACTTTCAGCGCCGTGGGTGAGGCCAGCATCTGCGAGGATGACTG
GAATTCCGGGGAGAGGTTACAGTGCACCGTGACCCACACAGACCTGCCCTCGCCACTGAAGCA
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GACCATCTCCCGGCCCAAGGGGGTGGCCCTGCACAGGCCCGATGTC'TACTTGCTGCCACCAGC
CCGGGAGCAGCTGAACCTGCGGGAGTCGGCCACCATCACGTGCCTGGTGACGGGCTTCTCTCC
CGCGGACGTCTTCGTGCAGTGGATGCAGAGGGGGCAGCCCTTG'TCCCCGAGAAGTATGTGAC
CAGCGCCCCAATGCCTGAGCCCCAGGCCCCAGGCCGGTACTTCGCCCACAGCATCCTGACCGT
GTCCGAAGAGGAATGGAACACGGGGGAGACCTACACCTGCGTGGTGGCCCATGAGGCCCTGCC
CAACAGGGTCACTGAGAGGACCGTGGACAAGTCCACCGAGGGGGAGGTGAGCGCCGACGAGGA
GGGCTTTGAGAACCTGTGGGCCACCGCCTCCACCTTCATCGTCCTCTTCCTCCTGAGCCTCTT
CTACAGTACCACCGTCACCTTGTTCAAGGTGAAATGAGTCGAC

designated herein as SEQ ID NO:14. PCR-amplified heavy chain variable regions may be inserted in-frame into unique BssHII (at nucleotides 96-100 of SEQ ID NO:15), and BstEII (nucleotides 106-112 of SEQ ID NO:16) sites, which are indicated above in bold.

[0188] Furthermore, pVHE may be used in those embodiments where it is desired to transfer polynucleotides isolated from the first library into a plasmid vector for subsequent selection of polynucleotides of the second library as described above.

[0189] Another preferred transfer plasmid of the present invention which comprises a polynucleotide encoding an immunoglobulin kappa light chain polypeptide through operable association with a vaccinia virus p7.5 promoter is pVKE, which comprises the sequence:

GGCCAAAATTGAAAACTAGATCTATTTATTGCACGCGGCCGCCCATGGGATGGAGCTGTAT
CATCCTCTTCTTGTTAGCAACAGCTACAGGC**GTGCAC**TTGA**CTCGAG**ATCAAACGAACTGTGG
CTGCACCATCTGTCTTCATCTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAAGTGCCTCTG
TTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAGGCCAAAGTACAGTGGAAGGTGGATAACG
CCCTCCAATCGGGTAAC'TCCAGGAGAGTGTACAGAGCAGGACAGCAAGGACAGCACCTACA
GCCTCAGCAGCACCTGACGCTGAGCAAAGCAGACTACGAGAAACACAAAGTCTACGCCTGCG
AAGTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGCTTCAACAGGGGAGAGTGTTAGG
TCGAC

designated herein as SEQ ID NO:17. PCR-amplified kappa light chain variable regions may be inserted in-frame into unique ApaLI (nucleotides 95-100 of SEQ ID NO:18), and XhoI (nucleotides 105-110 of SEQ ID NO:19) sites, which are indicated above in bold.

[0190] Furthermore, pVKE may be used in those embodiments where it is desired to have polynucleotides of the second library in a plasmid vector during the selection of polynucleotides of the first library as described above.

[0191] Another preferred transfer plasmid of the present invention which comprises a polynucleotide encoding an immunoglobulin lambda light chain polypeptide through operable association with a vaccinia virus p7.5 promoter is pVLE, which comprises the sequence:

GGCCAAAATTGAAAACTAGATCTATTTATTGCACGCGGCCGCCCATGGGATGGAGCTGTAT
CATCCTCTTCTTGGTAGCAACAGCTACAGGC**GTGCAC**TTGACTCGAGA**AAGCTT**ACCGTCCTAC
GAACTGTGGCTGCACCATCTGTCTTCATCTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAA
CTGCCTCTGTTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAGGCCAAAGTACAGTGAAGG
TGGATAACGCCCTCCAATCGGGTAACCTCCAGGAGAGTGTACAGAGCAGGACAGCAAGGACA
GCACCTACAGCCTCAGCAGCACCCCTGACGCTGAGCAAAGCAGACTACGAGAAACACAAAGTCT
ACGCCTGCGAAGTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGCTTCAACAGGGGAG
AGTGTTAGGTCGAC

designated herein as SEQ ID NO:20. PCR-amplified lambda light chain variable regions may be inserted in-frame into unique ApaLI (nucleotides 95-100 of SEQ ID NO:21) and HindIII (nucleotides 111-116 of SEQ ID NO:22) sites, which are indicated above in bold.

[0192] Furthermore, pVLE may be used in those embodiments where it is desired to have polynucleotides of the second library in a plasmid vector during the selection of polynucleotides of the first library as described above.

[0193] By "insert DNA" is meant one or more heterologous DNA segments to be expressed in the recombinant virus vector. According to the present invention, "insert DNAs" are polynucleotides which encode immunoglobulin subunit polypeptides. A DNA segment may be naturally occurring, non naturally occurring, synthetic, or a combination thereof. Methods of producing insert DNAs of the present invention are disclosed herein.

[0194] By "transfer plasmid" is meant a plasmid vector containing an insert DNA positioned between a 5' flanking region and a 3' flanking region as described above. The 5' flanking region shares homology with the first viral fragment, and the 3' flanking region shares homology with the second viral fragment.

Preferably, the transfer plasmid contains a suitable promoter, such as a strong, constitutive vaccinia promoter where the virus vector is a poxvirus, upstream of the insert DNA. The term "vector" means a polynucleotide construct containing a heterologous polynucleotide segment, which is capable of effecting transfer of that polynucleotide segment into a suitable host cell. Preferably the polynucleotide contained in the vector is operably linked to a suitable control sequence capable of effecting the expression of the polynucleotide in a suitable host. Such control sequences include a promoter to effect transcription, an optional operator sequence to control such transcription, a sequence encoding suitable mRNA ribosome binding sites, and sequences which control the termination of transcription and translation. As used herein, a vector may be a plasmid, a phage particle, a virus, a messenger RNA, or simply a potential genomic insert. Once transformed into a suitable host, the vector may replicate and function independently of the host genome, or may in some instances, integrate into the genome itself. Typical plasmid expression vectors for mammalian cell culture expression, for example, are based on pRK5 (EP 307,247), pSV16B (WO 91/08291) and pVL1392 (Pharmingen).

[0195] However, "a transfer plasmid," as used herein, is not limited to a specific plasmid or vector. Any DNA segment in circular or linear or other suitable form may act as a vehicle for transferring the DNA insert into a host cell along with the first and second viral "arms" in the tri-molecular recombination method. Other suitable vectors include lambda phage, mRNA, DNA fragments, etc., as described herein or otherwise known in the art. A plurality of plasmids may be a "primary library" such as those described herein for lambda.

[0196] Modifications of Trimolecular Recombination. Trimolecular recombination can be used to construct cDNA libraries in vaccinia virus with titers of the order of about 10^7 pfu. There are several factors that limit the complexity of these cDNA libraries or other libraries. These include: the size of the primary cDNA library or other library, such as a library of polynucleotides encoding immunoglobulin subunit polypeptides, that can be constructed in a plasmid vector, and the labor involved in the purification of large quantities

(hundreds of micrograms) of virus "arms," preferably vaccinia virus "arms" or other poxvirus "arms." Modifications of trimolecular recombination that would allow for vaccinia or other virus DNA recombination with primary cDNA libraries or other libraries, such as polynucleotides encoding immunoglobulin subunit polypeptides, constructed in bacteriophage lambda or DNA or phagemids derived therefrom, or that would allow separate virus DNA arms to be generated *in vivo* following infection with a modified viral vector could greatly increase the quality and titer of the eukaryotic virus cDNA libraries or other libraries that are constructed using these methods.

[0197] Transfer of cDNA inserts from a Bacteriophage Lambda Library to Vaccinia Virus. Lambda phage vectors have several advantages over plasmid vectors for construction of cDNA libraries or other libraries, such as polynucleotides encoding immunoglobulin subunit polypeptides. Plasmid cDNA (or other DNA insert) libraries or linear DNA libraries are introduced into bacteria cells by chemical/heat shock transformation, or by electroporation. Bacteria cells are preferentially transformed by smaller plasmids, resulting in a potential loss of representation of longer cDNAs or other insert DNA, such as polynucleotides encoding immunoglobulin subunit polypeptides, in a library. In addition, transformation is a relatively inefficient process for introducing foreign DNA or other DNA into a cell requiring the use of expensive commercially prepared competent bacteria in order to construct a cDNA library or other library, such as polynucleotides encoding immunoglobulin subunit polypeptides. In contrast, lambda phage vectors can tolerate cDNA inserts of 12 kilobases or more without any size bias. Lambda vectors are packaged into virions *in vitro* using high efficiency commercially available packaging extracts so that the recombinant lambda genomes can be introduced into bacterial cells by infection. This results in primary libraries with higher titers and better representation of large cDNAs or other insert DNA, such as polynucleotides encoding immunoglobulin subunit polypeptides, than is commonly obtained in plasmid libraries.

[0198] To enable transfer of cDNA inserts or other insert DNA, such as polynucleotides encoding immunoglobulin subunit polypeptides, from a library

constructed in a lambda vector to a eukaryotic virus vector such as vaccinia virus, the lambda vector must be modified to include vaccinia virus DNA sequences that allow for homologous recombination with the vaccinia virus DNA. The following example uses vaccinia virus homologous sequences, but other viruses may be similarly used. For example, the vaccinia virus HindIII J fragment (comprising the vaccinia tk gene) contained in plasmid p7.5/ATG0/tk (as described in Example 5, *infra*) can be excised using HindIII and SnaBI (3 kb of vaccinia DNA sequence), and subcloned into the HindIII/SnaBI sites of pT7Blue3 (Novagen cat no. 70025-3) creating pT7B3.Vtk. The vaccinia tk gene can be excised from this vector with SacI and SnaBI and inserted into the SacI/SmaI sites of Lambda Zap Express (Stratagene) to create lambda.Vtk. The lambda.Vtk vector will contain unique NotI, BamHI, SmaI, and SalI sites for insertion of cDNA downstream of the vaccinia 7.5k promoter. cDNA libraries can be constructed in lambda.Vtk employing methods that are well known in the art.

- [0199] DNA from a cDNA library or other library, such as polynucleotides encoding immunoglobulin subunit polypeptides, constructed in lambda.Vtk, or any similar bacteriophage that includes cDNA inserts or other insert DNA with flanking vaccinia DNA sequences to promote homologous recombination, can be employed to generate cDNA or other insert DNA recombinant vaccinia virus. Methods are well known in the art for excising a plasmid from the lambda genome by coinfection with a helper phage (ExAssist phage, Stratagene cat no. 211203). Mass excision from a lambda based library creates an equivalent cDNA library or other library in a plasmid vector. Plasmids excised from, for example, the lambda.Vtk cDNA library will contain the vaccinia tk sequences flanking the cDNA inserts or other insert DNAs, such as polynucleotides encoding immunoglobulin subunit polypeptides. This plasmid DNA can then be used to construct vaccinia recombinants by trimolecular recombination. Another embodiment of this method is to purify the lambda DNA directly from the initial lambda.Vtk library, and to transfect this recombinant viral (lambda) DNA or fragments thereof together with the two large vaccinia virus DNA fragments for trimolecular recombination.

- [0200] Generation of vaccinia arms *in vivo*. Purification and transfection of vaccinia DNA or other virus DNA “arms” or fragments is a limiting factor in the construction of polynucleotide libraries by trimolecular recombination. Modifications to the method to allow for the requisite generation of virus arms, in particular vaccinia virus arms, *in vivo* would allow for more efficient construction of libraries in eukaryotic viruses.
- [0201] Host cells can be modified to express a restriction endonuclease that recognizes a unique site introduced into a virus vector genome. For example, when a vaccinia virus infects these host cells, the restriction endonuclease will digest the vaccinia DNA, generating “arms” that can only be repaired, *i.e.*, rejoined, by trimolecular recombination. Examples of restriction endonucleases include the bacterial enzymes NotI and ApaI, the Yeast endonuclease VDE (R. Hirata, Y. Ohsumi, A. Nakano, H. Kawasaki, K. Suzuki, Y. Anraku. 1990 *J. Biological Chemistry* 265: 6726-6733), the *Chlamydomonas eugametos* endonuclease I-CeuI and others well-known in the art. For example, a vaccinia strain containing unique NotI and ApaI sites in the *tk* gene has already been constructed, and a strain containing unique VDE and/or I-CeuI sites in the *tk* gene could be readily constructed by methods known in the art.
- [0202] Constitutive expression of a restriction endonuclease would be lethal to a cell, due to the fragmentation of the chromosomal DNA by that enzyme. To avoid this complication, in one embodiment host cells are modified to express the gene(s) for the restriction endonuclease(s) under the control of an inducible promoter.
- [0203] A preferred method for inducible expression utilizes the Tet-On Gene Expression System (Clontech). In this system expression of the gene encoding the endonuclease is silent in the absence of an inducer (tetracycline). This makes it possible to isolate a stably transfected cell line that can be induced to express a toxic gene, *i.e.*, the endonuclease (Gossen, M. *et al.*, *Science* 268: 1766-1769 (1995)). The addition of the tetracycline derivative doxycycline induces expression of the endonuclease. In a preferred embodiment, BSC1 host cells will be stably transfected with the Tet-On vector controlling expression of the NotI

gene. Confluent monolayers of these cells will be induced with doxycycline and then infected with v7.5/tk (unique NotI site in *tk* gene), and transfected with cDNA or insert DNA recombinant transfer plasmids or transfer DNA or lambda phage or phagemid DNA. Digestion of exposed vaccinia DNA at the unique NotI site, for example, in the *tk* gene or other sequence by the NotI endonuclease encoded in the host cells produces two large vaccinia DNA fragments which can give rise to full-length viral DNA only by undergoing trimolecular recombination with the transfer plasmid or phage DNA. Digestion of host cell chromosomal DNA by NotI is not expected to prevent production of modified infectious viruses because the host cells are not required to proliferate during viral replication and virion assembly.

- [0204] In another embodiment of this method to generate virus arms such as vaccinia arms *in vivo*, a modified vaccinia strain is constructed that contains a unique endonuclease site in the *tk* gene or other non-essential gene, and also contains a heterologous polynucleotide encoding the endonuclease under the control of the T7 bacteriophage promoter at another non-essential site in the vaccinia genome. Infection of cells that express the T7 RNA polymerase would result in expression of the endonuclease, and subsequent digestion of the vaccinia DNA by this enzyme. In a preferred embodiment, the v7.5/tk strain of vaccinia is modified by insertion of a cassette containing the cDNA encoding NotI with expression controlled by the T7 promoter into the HindIII C or F region (Coupar, E.H.B. *et al.*, *Gene* 68: 1-10 (1988); Flexner, C. *et al.*, *Nature* 330: 259-262 (1987)), generating v7.5/tk/T7NotI. A cell line is stably transfected with the cDNA encoding the T7 RNA polymerase under the control of a mammalian promoter as described (O. Elroy-Stein, B. Moss. 1990 *Proc. Natl. Acad. Sci. USA* 87: 6743-6747). Infection of this packaging cell line with v7.5/tk/T7NotI will result in T7 RNA polymerase dependent expression of NotI, and subsequent digestion of the vaccinia DNA into arms. Infectious full-length viral DNA can only be reconstituted and packaged from the digested vaccinia DNA arms following trimolecular recombination with a transfer plasmid or phage DNA. In yet another embodiment of this method, the T7 RNA polymerase can be provided

by co-infection with a T7 RNA polymerase recombinant helper virus, such as fowlpox virus (P. Britton, P. Green, S. Kottier, K.L. Mawditt, Z. Penzes, D. Cavanagh, M.A. Skinner. 1996 *J. General Virology* 77: 963-967).

[0205] A unique feature of trimolecular recombination employing these various strategies for generation of large virus DNA fragments, preferably vaccinia DNA fragments *in vivo* is that digestion of the vaccinia DNA may, but does not need to precede recombination. It suffices that only recombinant virus escapes destruction by digestion. This contrasts with trimolecular recombination employing transfection of vaccinia DNA digested *in vitro* where, of necessity, vaccinia DNA fragments are created prior to recombination. It is possible that the opportunity for bimolecular recombination prior to digestion will yield a greater frequency of recombinants than can be obtained through trimolecular recombination following digestion.

[0206] Selection and Screening Strategies for Isolation of Recombinant Immunoglobulin Molecules Using Virus Vectors, Especially Poxviruses. In certain embodiments of the present invention, the trimolecular recombination method is used in the production of libraries of polynucleotides expressing immunoglobulin subunit polypeptides. In this embodiment, libraries comprising full-length immunoglobulin subunit polypeptides, or fragments thereof, are prepared by first inserting cassettes encoding immunoglobulin constant regions and signal peptides into a transfer plasmid which contains 5' and 3' regions homologous to vaccinia virus. Rearranged immunoglobulin variable regions are isolated by PCR from pre-B cells from unimmunized animals or from B cells or plasma cells from immunized animals. These PCR fragments are cloned between, and in frame with the immunoglobulin signal peptide and constant region, to produce a coding region for an immunoglobulin subunit polypeptide. These transfer plasmids are introduced into host cells with poxvirus "arms," and the tri-molecular recombination method is used to produce the libraries.

[0207] The present invention provides a variety of methods for identifying, *i.e.*, selecting or screening for immunoglobulin molecules with a desired specificity, where the immunoglobulin molecules are produced *in vitro* in eukaryotic cells.

These include selecting for host cell effects such as antigen-induced cell death and antigen-induced signaling, screening pools of host cells for antigen-specific binding, and screening the medium in which pools of host cells are grown for the presence of soluble immunoglobulin molecules with a desired antigenic specificity or a desired functional characteristic.

[0208] As disclosed in detail herein, methods are provided to identify immunoglobulin molecules, or antigen-specific fragments thereof expressed in eukaryotic cells on the basis of either antigen-induced cell death, antigen-induced signaling, antigen-specific binding, or other antigen-specific functions. The selection and screening techniques of the present invention eliminate the bias imposed by selection of antibodies in rodents or the limitations of synthesis and assembly in bacteria.

[0209] Many of the identification methods described herein depend on expression of host cell genes or host cell transcriptional regulatory regions, which directly or indirectly induce cell death or produce a detectable signal in response to antigen binding to immunoglobulin molecules, or antigen-specific fragments thereof, expressed on the surface of the host cells. It is important to note that most preferred embodiments of the present invention require that host cells be infected with a eukaryotic virus vector, preferably a poxvirus vector, and even more preferably a vaccinia virus vector. It is well understood by those of ordinary skill in the art that some host cell protein synthesis is rapidly shut down upon poxvirus infection in some cell lines, even in the absence of viral gene expression. This is problematic if upregulation of host cell genes or host cell transcriptional regulatory regions is required in order to induce antigen-induced cell death or cell signaling. This problem is not intractable, however, because in certain cell lines, inhibition of host protein synthesis remains incomplete until after viral DNA replication. See Moss, B., "Poxviridae and their Replication" IN *Virology*, 2d Edition, B.N. Fields, D.M. Knipe *et al.*, Eds., Raven Press, p. 2096 (1990). There is a need, however, to rapidly screen a variety of host cells for their ability to express gene products which are upregulated upon cross linking of surface-expressed immunoglobulin molecules upon infection by a eukaryotic virus

vector, preferably a poxvirus vector, and even more preferably a vaccinia virus vector; and to screen desired host cells for differential expression of cellular genes upon virus infection with various mutant and attenuated viruses.

[0210] Accordingly, a method is provided for screening a variety of host cells for the expression of host cell genes and/or the operability of host cell transcriptional regulatory regions effecting antigen-induced cell death or cell signaling, upon infection by a virus vector, through expression profiling of particular host cells in microarrays of ordered cDNA libraries. Expression profiling in microarrays is described in Duggan, D.J., *et al.*, *Nature Genet.* 21(1 Suppl):10-14 (1999), which is incorporated herein by reference in its entirety.

[0211] According to this method, expression profiling is used to compare host cell gene expression patterns in uninfected host cells and host cells infected with a eukaryotic virus expression vector, preferably a poxvirus vector, even more preferably a vaccinia virus vector, where the particular eukaryotic virus vector is the vector used to construct said first and said second libraries of polynucleotides of the present invention. In this way, suitable host cells capable of expressing immunoglobulin molecules, or antigen-specific fragments thereof on their surface, and which further continue to undergo expression of the necessary inducible proteins upon infection with a given virus, can be identified.

[0212] Expression profiling is also used to compare host cell gene expression patterns in a given host cell, for example, comparing expression patterns when the host cell is infected with a fully infectious virus vector, and when the host cell is infected with a corresponding attenuated virus vector. Expression profiling in microarrays allows large-scale screening of host cells infected with a variety of attenuated viruses, where the attenuation is achieved in a variety of different ways. For example, certain attenuations are achieved through genetic mutation. Many vaccinia virus mutants have been characterized. These may be fully defective mutants, *i.e.*, the production of infectious virus particles requires helper virus, or they may be conditional mutants, *e.g.*, temperature sensitive mutants. Conditional mutants are particularly preferred, in that the virus-infected host cells can be maintained in a non-permissive environment, *e.g.*, at a non-permissive

temperature, during the period where host gene expression is required, and then shifted to a permissive environment, *e.g.*, a permissive temperature, to allow virus particles to be produced. Alternatively, a fully infectious virus may be "attenuated" by chemical inhibitors which reversibly block virus replication at defined points in the infection cycle. Chemical inhibitors include, but are not limited to hydroxyurea and 5-fluorodeoxyuridine. Virus-infected host cells are maintained in the chemical inhibitor during the period where host gene expression is required, and then the chemical inhibitor is removed to allow virus particles to be produced.

[0213] Using this method, expression profiling in microarrays may be used to identify suitable host cells, suitable transcription regulatory regions, and/or suitable attenuated viruses in any of the selection methods described herein.

[0214] In one embodiment, a selection method is provided to select polynucleotides encoding immunoglobulin molecules, or antigen-specific fragments thereof, based on direct antigen-induced apoptosis. According to this method, a host cell is selected for infection and/or transfection that is an early B cell lymphoma. Suitable early B cell lymphoma cell lines include, but are not limited to CH33 cells, CH31 cells (Pennell, C.A., *et al.*, *Proc. Natl. Acad. Sci. USA* 82:3799-3803 (1985)), or WEHI-231 cells (Boyd, A.W. and Schrader, J.W. *J. Immunol.* 126:2466-2469 (1981)). Early B cell lymphoma cell lines respond to crosslinking of antigen-specific immunoglobulin by induction of spontaneous growth inhibition and apoptotic cell death (Pennell, C.A., and Scott, D.W. *Eur. J. Immunol.* 16:1577-1581 (1986); Tisch, R., *et al.*, *Proc. Natl. Acad. Sci. USA* 85:69114-6918 (1988); Ales-Martinez, J.E., *et al.*, *Proc. Natl. Acad. Sci. USA* 85:69119-6923 (1988); Warner, G.L., and Scott, D.W. *Cell. Immunol.* 115:195-203 (1988)). Following infection and/or transfection with the first and second polynucleotide libraries as described above, synthesis and assembly of antibody molecules is allowed to proceed for a time period ranging from about 5 hours to about 48 hours, preferably for about 6 hours, about 10 hours, about 12 hours, about 16 hours about 20 hours, about 24 hours about 30 hours, about 36 hours, about 40 hours, or about 48 hours, even more preferably for about 12 hours or for

about 24 hours; at which time the host cells are contacted with specific antigen, in order to cross-link any specific immunoglobulin receptors (*i.e.*, membrane-bound immunoglobulin molecules, or antigen-specific fragments thereof) and induce apoptosis in those immunoglobulin expressing host cells which directly respond to cross-linking of antigen-specific immunoglobulin by induction of growth inhibition and apoptotic cell death. Host cells which have undergone apoptosis, or their contents, including the polynucleotides encoding an immunoglobulin subunit polypeptide which are contained therein, are recovered, thereby enriching for polynucleotides of the first library which encode a first immunoglobulin subunit polypeptide which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, specifically binds the antigen of interest.

[0215] Upon further selection and enrichment steps for polynucleotides of the first library, and isolation of those polynucleotides, a similar process is carried out to recover polynucleotides of the second library which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, bind the desired specific antigen.

[0216] An example of this method is shown in Fig. 1. A "first library" of polynucleotides encoding diverse heavy chains from antibody producing cells of either naïve or immunized donors is constructed in a poxvirus vector, preferably a vaccinia virus vector, and a similarly diverse "second library" of polynucleotides encoding immunoglobulin light chains is constructed in a plasmid vector in which expression of the polynucleotides is regulated by a vaccinia promoter, preferably a synthetic early/late promoter, for example the p11 promoter, or the p7.5 promoter. Preferably for this embodiment, the immunoglobulin heavy chain constant region encoded by the pox virus constructs is designed to retain the transmembrane region that results in expression of immunoglobulin receptor on the surface membrane. Eukaryotic cells, preferably early B cell lymphoma cells, are infected with the pox virus heavy chain library at a multiplicity of infection of about 1 (MOI=1). Two hours later the infected cells are transfected with the light chain plasmid library under conditions which

allow, on average, 10 or more separate light chain recombinant plasmids to be taken up and expressed in each cell. Because expression of the recombinant gene in this plasmid is regulated by a vaccinia virus promoter, high levels of the recombinant gene product are expressed in the cytoplasm of vaccinia virus infected cells without a requirement for nuclear integration. In addition, a sequence independent mechanism for amplification of circular DNA in the cytoplasm of vaccinia virus infected cell results in even higher concentrations of the transfected light chain recombinant plasmids (Merchlinsky, M., and Moss, B. *Cancer Cells* 6:87-93 (1988)). These two factors contribute to the high levels of expression that result in excess light chain synthesis.

[0217] Another preferred embodiment utilizes a T7 phage promoter, which is active in cells in which T7 RNA polymerase is expressed, for the regulation of the expression of polynucleotides encoding a "first library" of polynucleotides encoding diverse heavy chains from antibody producing cells of either naïve or immunized donors constructed in a poxvirus vector, preferably a vaccinia virus vector, and a similarly diverse "second library" of polynucleotides encoding immunoglobulin light chains is constructed in a plasmid vector (Eckert D. and Merchlinsky M. *J Gen Virol.* 80 (Pt 6):1463-9 (1999); Elroy-Stein O., Fuerst T.R. and Moss B. *Proc Natl Acad Sci U S A.* 86(16):6126-30 (1989); Fuerst T.R., Earl P.L. and Moss B. *Mol Cell Biol.* 7(7):2538-44 (1987); Elroy-Stein O. and Moss B. *Proc Natl Acad Sci U S A.* 87(17):6743-7 (1990); Cottet S. and Cortesey B. *Eur J Biochem* 246(l):23-31.).

[0218] As will be readily appreciated by those of ordinary skill in the art, kinetic considerations are very important in the design of this experiment as the pox virus derived expression vector is itself cytopathic in a time frame of about 1 to 10 days, more usually about 2 to 8 days, 2 to 6 days, or 2 to 4 days, depending on the virus vector used, the particular host cell, and the multiplicity of infection. In a preferred embodiment, a B cell lymphoma is selected for which the apoptotic response to surface immunoglobulin crosslinking is rapid relative to the natural cytopathic effects of pox virus infection in that cell. Accordingly, it is preferred that apoptosis in response to antigen-induced cross-linking of immunoglobulin

molecules on the surface of the host cells occurs within a period between about 1 hour to about 4 days after contacting the host cells with antigen, so as to precede induction of CPE. More preferably, apoptosis occurs within about 1 hour about 2 hours, about 3 hours about 4 hours, about 5 hours, about 6 hours, about 7 hours, about 8 hours, about 9 hours, about 10 hours, about 11 hours, about 12 hours, about 14 hours, about 16 hours, about 18 hours, about 20 hours, about 22 hours, about 24 hours, about 28 hours, about 32 hours, about 36 hours, about 40 hours, about 44 hours, or about 48 hours after contacting the host cells with antigen. Even more preferably apoptosis is induced within about 12 hours of contacting the host cells with antigen. Alternatively, an attenuated poxvirus vector is employed with a much slower kinetics of induction of cytopathic effects. Attenuated poxvirus vectors are disclosed herein.

[0219] According to this method, host cells which express antigen-specific immunoglobulins on their surface are selected upon undergoing apoptosis. For example, if the host cells are attached to a solid substrate, those cells which undergo apoptosis are released from the substrate and are recovered by harvesting the liquid medium in which the host cells are cultured. Alternatively, the host cells are attached to a solid substrate, and those cells which undergo apoptosis undergo a lytic event, thereby releasing their cytoplasmic contents into the liquid medium in which the host cells are cultured. Virus particles released from these cells can then be harvested in the liquid medium.

[0220] A host cell containing a polynucleotide encoding an immunoglobulin subunit polypeptide may become "nonadherent" or "nonviable" by any mechanism, which may include lysis, inability to adhere, loss of viability, loss of membrane integrity, loss of structural stability, disruption of cytoskeletal elements, inability to maintain membrane potential, arrest of cell cycle, inability to generate energy, etc. Thus, host cells containing target polynucleotides may be recovered, *i.e.*, separated from remaining cells, by any physical means such as aspiration, washing, filtration, centrifugation, cell sorting, fluorescence activated cell sorting (FACS), etc.

[0221] For example, host cells containing polynucleotides encoding immunoglobulin subunit polypeptides may lyse and thereby release recombinant virus particles, preferably poxvirus particles even more preferably vaccinia virus particles into the culture media or may become nonadherent and therefore lift away from the solid support. Thus, in a preferred embodiment, released recombinant viruses and/or nonadherent cells are separated from adherent cells by aspiration or washing.

[0222] Where the host cells are an early B cell lymphoma cell line, the cells may be attached to a solid substrate through interaction with a B cell-specific antibody which has been bound to the substrate. Suitable B cell-specific antibodies include, but are not limited to an anti-CD 19 antibody and an anti-CD 20 antibody.

[0223] In other preferred embodiments, antigen-induced cell death is effected directly or indirectly by employing a host cell transfected with a construct in which a foreign polynucleotide, the expression of which indirectly results in cell death, is operably associated with a transcriptional regulatory region which is induced upon cross-linking of surface immunoglobulin molecules.

[0224] By a "transcriptional regulatory region induced upon cross-linking of surface immunoglobulin molecules" is meant a region, for example, a host cell promoter, which normally regulates a gene that is upregulated in the host cell upon cross linking of surface-expressed immunoglobulin molecules. A preferred example of such a transcriptional regulatory region is the BAX promoter, which is upregulated in early B cell lymphoma cells upon cross linking of surface immunoglobulin molecules.

[0225] In one embodiment, illustrated in Fig. 2A and Fig. 2B, a method is provided to induce cell death upon expression of a foreign polynucleotide encoding a cytotoxic T cell (CTL) epitope. The foreign polynucleotide encoding the CTL epitope is placed in operable association with a transcriptional regulatory region which is induced upon cross-linking of surface immunoglobulin molecules. Upon antigen-induced cross-linking of immunoglobulin molecules

of the surface of host cells, the CTL epitope is expressed on the surface of the host cell in the context of a defined MHC molecule, also expressed on the surface of the host cell. The cells are contacted with epitope-specific CTLs which recognize the CTL epitope in the context of the defined MHC molecule, and the cells expressing the CTL epitope rapidly undergo a lytic event. Methods of selecting and recovering host cells expressing specific CTL epitopes are further disclosed in Zauderer, PCT Publication No. WO 00/028016.

[0226] Selection of the host cells is accomplished through recovering those cells, or the contents thereof, which have succumbed to cell death and/or have undergone a lytic event. For example, if host cells are chosen which grow attached to a solid support, those host cells which succumb to cell death and/or undergo a lytic event will be released from the support and can be recovered in the cell supernatant. Alternatively virus particles released from host cells which have succumbed to cell death and/or undergone a lytic event may be recovered from the cell supernatant.

[0227] According to this embodiment, the MHC molecule expressed on the surface of the host cells may be either a class I MHC molecule or a class II MHC molecule. In a particularly preferred embodiment, the MHC molecule expressed on the host cells is an H-2K^d molecule, and the CTL epitope which is expressed upon antigen-induced cross linking is the peptide GYKAGMIHI, designated herein as SEQ ID NO:23.

[0228] In utilizing this method, any host cell which is capable of expressing immunoglobulin molecules, or antigen-specific fragments thereof, on its surface may be used. Suitable host cells include immunoglobulin-negative plasmacytoma cell lines. Examples of such cell lines include, but are not limited to, an NS1 cell line, an Sp2/0 cell line, and a P3 cell line. Other suitable cell lines will be apparent to those of ordinary skill in the art.

[0229] In another preferred embodiment, also illustrated in Fig. 2A and Fig. 2B, a method is provided wherein cell death is induced indirectly by employing a host cell transfected with a construct in which the a heterologous polynucleotide

comprising a "suicide" gene is operably associated with a transcriptional regulatory region which is induced upon cross-linking of surface immunoglobulin molecules. By "suicide gene" is meant a nucleic acid molecule which causes cell death when expressed. Polynucleotides useful as suicide genes include many cell death-inducing sequences which are known in the art. Preferred suicide genes are those which encode toxins such as *Pseudomonas* exotoxin A chain, diphtheria A chain, ricin A chain, abrin A chain, modeccin A chain, and alpha-sarcin. A preferred suicide gene encodes the diphtheria A toxin subunit. Upon antigen-induced cross-linking of immunoglobulin molecules of the surface of host cells, the promoter of the apoptosis induced gene is induced, thereby allowing expression of the suicide gene, and thereby promoting cell death.

[0230] In utilizing this method, any host cell may be used which is capable of expressing immunoglobulin molecules, or antigen-specific fragments thereof, on its surface, and in which a transcriptional regulatory region can be identified by expression profiling, which is induced upon cross-linking of surface immunoglobulin molecules. Suitable host cells include early B cell lymphoma cell lines and immunoglobulin-negative plasmacytoma cell lines. Examples of such cell lines include, but are not limited to, a CH33 cell line, a CH 31 cell line, a WEHI-231 cell line, an NS1 cell line, an Sp2/0 cell line, and a P3 cell line. Other suitable cell lines will be apparent to those of ordinary skill in the art.

[0231] Where the host cells are an Ig-negative plasmacytoma cell line, the cells may be attached to a solid substrate through interaction with a plasmacytoma-specific antibody which has been bound to the substrate. Suitable plasmacytoma-specific antibodies include, but are not limited to an anti-CD38 antibody (Yi, Q., *et al.*, *Blood* 90:1960-1967 (1997)), an anti-CD31 antibody (Medina, F., *et al.*, *Cytometry* 39:231-234 (2000)), an anti-CD20 antibody (Haghighi, B., *et al.*, *Am. J. Hematol.* 59:302-308 (1998)), and an anti-CD10 antibody (Dunphy, C.H., *Acta. Cytol.* 40:358-362 (1996)).

[0232] Direct and indirect antigen-induced cell death methods as described herein may also be combined. For example, in those embodiments where the host cell is an early B cell lymphoma, and antigen cross-linking directly induces apoptosis,

antigen-induced cell death may be accelerated by transfecting the early B cell lymphoma host cell with a construct in which the a polynucleotide encoding a foreign cytotoxic T cell epitope is operably associated with a transcriptional regulatory region which is induced upon cross-linking of surface immunoglobulin molecules. Upon contacting antigen cross-linked cells with specific cytotoxic T cells as described, cell death is accelerated. Similarly, in those embodiments where the host cell is an early B cell lymphoma, and antigen cross-linking directly effects apoptosis as described above, antigen-induced cell death may be accelerated by transfecting the early B cell lymphoma host cell with a construct in which a suicide gene is operably associated with a transcriptional regulatory region which is induced upon cross-linking of surface immunoglobulin molecules.

- [0233] Immunoglobulin heavy chains can be modified so that a specific antigen will induce a readily detectable signal in cells in which the receptor is crosslinked by specific antigen. A preferred embodiment is to use an apoptosis induction system to select for cell killing as a consequence of expression of an antigen-specific receptor. An example of an apoptosis induction system involves the human FAS (CD95, APO-1) receptor, which is a member of the tumor necrosis-nerve growth factor receptor superfamily recognized for its role in regulating apoptosis through recruitment and assembly of a death-inducing signaling complex that activates a cascade of proteolytic caspases. Several reports have described a FAS-based inducible cell death system whereby apoptosis could be induced through chimeric proteins containing the cytoplasmic "death domain" of FAS coupled to various receptors allowing for induction of apoptosis through a variety of cell modulators. Ishiwatari-Hayasaka *et al.* have successfully used the extracellular domain of mouse CD44 with human FAS to induce apoptosis upon cross-linking with polyvalent anti-CD44 antibodies (Ishiwatari-Hayasaka H. *et al. J Immunol* 163:1258-64 (1999)). In addition, Takahashi *et al.* have demonstrated that a chimeric human G-CSFR/FAS (extracellular /cytoplasmic) protein is capable of inducing apoptosis upon cross-linking with anti-G-CSFR antibodies (Takahashi T. *et al. J Biol Chem* 271:17555-60 (1996)). These

authors also demonstrate that the chimeric protein is incapable of inducing apoptosis as a dimer. The complex must be in at least a trimeric form.

[0234] In a preferred embodiment, a chimeric gene is constructed in which the transmembrane domain and cytoplasmic death domain of FAS is fused to the carboxyl terminus of the CH1 domain of the human IgM heavy chain (CH1-Fas, Fig. 13 (a)). Diverse VH genes are inserted into this construct as described herein to create a library of VH-CH1-Fas recombinant vaccinia virus. Membrane receptors with VH-CH1-Fas are assembled in host cells which are infected with the VH-CH1-Fas constructs and which are transfected with DNA encoding diverse immunoglobulin light chains or which are infected with psoralin treated recombinant vaccinia virus encoding diverse immunoglobulin light chains. Those cells that express a combination of heavy and light chain variable region genes with a desired specificity will have some of their membrane receptors crosslinked in the presence of the specific immobilized antigen of interest. Apoptosis will be induced as a result of formation of functional complexes of VHCH1/FAS oligomers. Trimer formation can occur through crosslinking with polyvalent antigens or through immobilization of more than one antigen to tissue culture plates or beads.

[0235] In an alternative embodiment, the VH library is expressed in fusion proteins in which a polypeptide comprising the transmembrane domain and cytoplasmic death domain of FAS is fused to the carboxyl terminus of the IgM heavy chain CH4 domain (Fig. 13 (b)). In yet another embodiment, the cytoplasmic death domain of FAS is fused to the carboxyl terminus of the IgM heavy chain transmembrane domain following the CH4 domain (Fig. 13 (c)).

[0236] The latter two embodiments (Fig. 13 (b and c)) result in synthesis of an already dimeric Fas death domain which facilitates formation of trimeric complexes required for induction of the apoptotic signal and thereby increases the number of antigen-specific receptors selected. Use of the monomeric construct (Fig. 13(a)), however, results in selection of fewer but higher affinity antigen receptors, and also reduces the background of non-antigen specific cell death. The two receptors with dimeric Fas domains differ in terms of whether the

transmembrane region encoded in the fusion protein is Fas-derived or IgM-derived. An IgM-derived transmembrane region may function more efficiently for membrane receptor expression in cells of the B lymphocyte lineage. An advantage of this embodiment, however, is that it is not limited to B cells. In particular, the monomeric Fas construct is synthesized and expressed as a membrane receptor in a wide variety of cell types including epithelial cell lines, Hela cells and BSC-1 cells in which high titers of vaccinia virus can be generated.

[0237] In another embodiment, a screening method is provided to recover polynucleotides encoding immunoglobulin molecules, or antigen-specific fragments thereof, based on antigen-induced cell signaling. According to this method, host cells are transfected with an easily detected reporter construct, for example luciferase, operably associated with a transcriptional regulatory region which is upregulated as a result of surface immunoglobulin crosslinking. Pools of host cells expressing immunoglobulins or fragments thereof on their surface are contacted with antigen, and upon cross linking, the signal is detected in that pool. Referring to the first step in the immunoglobulin identification method as described above, the signaling method may be carried out as follows. The first library of polynucleotides encoding immunoglobulin subunit polypeptides is divided into a plurality of pools, *e.g.*, about 2, 5, 10, 25, 15, 75, 100, or more pools, each pool containing about 10, 100, 10^3 , 10^4 , 10^5 , 10^6 , 10^7 , 10^8 , or 10^9 different polynucleotides encoding immunoglobulin subunit polypeptides with different variable regions. Preferred pools initially contain about 10^3 polynucleotides each. Each pool is expanded and a replicate aliquot is set aside for later recovery. Where the pools of polynucleotides are constructed in virus vectors, preferably poxvirus vectors, and even more preferably vaccinia virus vectors, the pools are prepared, *e.g.*, by diluting a high-titer stock of the virus library and using the portions to infect microcultures of tissue culture cells at a low MOI, *e.g.*, MOI < 0.1. Typically a greater than 1,000 fold expansion in the viral titer is obtained after 48 hrs infection. Expanding viral titers in multiple individual pools mitigates the risk that a subset of recombinants will be lost due to relatively rapid growth of a competing subset.

[0238] The virus pools are then used to infect pools of host cells equal to the number of virus pools prepared. These host cells have been engineered to express a reporter molecule as a result of surface immunoglobulin crosslinking. The number of host cells infected with each pool depends on the number of polynucleotides contained in the pool, and the MOI desired. The second library of polynucleotides is also introduced into the host cell pools, and expression of immunoglobulin molecules or fragments thereof on the surface of the host cells is permitted.

[0239] The host cell pools are then contacted with a desired antigen under conditions wherein host cells expressing antigen-specific immunoglobulin molecules on their surface express the detectable reporter molecule upon cross-linking of said immunoglobulin molecules, and the various pools of host cells are screened for expression of the reporter molecule. Those pools of host cells in which reporter expression is detected are harvested, and the polynucleotides of the first library contained therein are recovered from the aliquot previously set aside following initial expansion of that pool of polynucleotides.

[0240] To further enrich for polynucleotides of the first library which encode antigen-specific immunoglobulin subunit polypeptides, the polynucleotides recovered above are divided into a plurality of sub-pools. The sub-pools are set to contain fewer different members than the pools utilized above. For example, if each of the first pools contained 10^3 different polynucleotides, the sub-pools are set up so as to contain, on average, about 10 or 100 different polynucleotides each. The sub-pools are introduced into host cells with the second library as above, and expression of immunoglobulin molecules, or fragments thereof, on the membrane surface of the host cells is permitted. The host cells are then contacted with antigen as above, and those sub-pools of host cells in which expression of the reporter molecule is detected are identified, and the polynucleotides of the first library contained therein are recovered from the replicate pools previously set aside as described above. It will be appreciated by those of ordinary skill in the art that this process may be repeated one or more additional times in order to

adequately enrich for polynucleotides encoding antigen-specific immunoglobulin subunit polypeptides.

[0241] Upon further selection and enrichment steps for polynucleotides of the first library, and isolation of those polynucleotides, a similar process is carried out to recover polynucleotides of the second library which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, bind the desired specific antigen.

[0242] Any suitable reporter molecule may be used in this method, the choice depending upon the host cells used, the detection instruments available, and the ease of detection desired. Suitable reporter molecules include, but are not limited to luciferase, green fluorescent protein, and beta-galactosidase.

[0243] Any host cell capable of expressing immunoglobulin molecules on its surface may be used in this method. Preferred host cells include immunoglobulin-negative plasmacytoma cells, *e.g.*, NS1 cells, Sp2/0 cells, or P3 cells, and early B-cell lymphoma cells.

[0244] Similar to the cell death methods described above, kinetic considerations dictate that expression of the reporter construct take place prior to the induction of CPE. Nonetheless, it is preferred that expression of a detectable reporter molecule in response to antigen-induced cross-linking of immunoglobulin molecules on the surface of the host cells occurs within a period between about 1 hour to about 4 days after contacting the host cells with antigen, so as to precede induction of CPE. More preferably, reporter molecule expression occurs within about 1 hour about 2 hours, about 3 hours about 4 hours, about 5 hours, about 6 hours, about 7 hours, about 8 hours, about 9 hours, about 10 hours, about 11 hours, about 12 hours, about 14 hours, about 16 hours, about 18 hours, about 20 hours, about 22 hours, about 24 hours, about 28 hours, about 32 hours, about 36 hours, about 40 hours, about 44 hours, or about 48 hours after contacting the host cells with antigen. Even more preferably reporter molecule expression occurs within about 12 hours of contacting the host cells with antigen.

[0245] By a "transcriptional regulatory region induced upon cross-linking of surface immunoglobulin molecules" is meant a region, for example, a host cell promoter, which normally regulates a gene that is upregulated in the host cell upon cross linking of surface-expressed immunoglobulin molecules. A preferred example of such a transcriptional regulatory region is the BAX promoter, which is upregulated in early B cell lymphoma cells upon cross linking of surface immunoglobulin molecules.

[0246] In yet another embodiment, a selection or screening method is provided to select polynucleotides encoding immunoglobulin molecules, or antigen-specific fragments thereof, based on antigen-specific binding. This embodiment is illustrated in Fig. 5. According to this method, host cells which express antigen-specific immunoglobulin molecules, or fragments thereof on their surface are recovered based solely on the detection of antigen binding. Antigen binding may be utilized as a selection method, *i.e.*, where host cells expressing antigen-specific immunoglobulin molecules are directly selected by virtue of binding antigen, by methods similar to those described for selection based on cell death as described above. For example, if an antigen is bound to a solid substrate, host cells in suspension which bind the antigen may be recovered by binding, through the antigen, to the solid substrate. Alternatively, antigen binding may be used as a screening process, *i.e.*, where pools of host cells are screened for detectable antigen binding by methods similar to that described above for antigen-induced cell signaling. For example, pools of host cells expressing immunoglobulins or fragments thereof on their surface are contacted with antigen, and antigen binding in a given pool is detected through an immunoassay, for example, through detection of an enzyme-antibody conjugate which binds to the antigen.

[0247] Referring to the first step in the immunoglobulin identification methods as described above, selection via the antigen-specific binding method may be carried out as follows. A host cell is selected for infection and/or transfection that is capable of high level expression of immunoglobulin molecules on its surface. Preferably, the host cell grows in suspension. Following infection with the first and second polynucleotide libraries as described above, synthesis and assembly

of antibody molecules is allowed to proceed. The host cells are then transferred into microtiter wells which have antigen bound to their surface. Host cells which bind antigen thereby become attached to the surface of the well, and those cells that remain unbound are removed by gentle washing. Alternatively, host cells which bind antigen may be recovered, for example, by fluorescence-activated cell sorting (FACS). FACS, also called flow cytometry, is used to sort individual cells on the basis of optical properties, including fluorescence. It is useful for screening large populations of cells in a relatively short period of time. Finally the host cells which bound to the antigen are recovered, thereby enriching for polynucleotides of the first library which encode a first immunoglobulin subunit polypeptide which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, specifically binds the antigen of interest.

[0248] Upon further selection and enrichment steps for polynucleotides of the first library, and isolation of those polynucleotides, a similar process is carried out to recover polynucleotides of the second library which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, bind the desired specific antigen.

[0249] Any host cell capable of expressing immunoglobulin molecules on its surface may be used in this selection method. Preferred host cells include immunoglobulin-negative plasmacytoma cells, *e.g.*, NS1 cells, Sp2/0 cells, or P3 cells, and early B-cell lymphoma cells. It is preferred that the cells are capable of growth in suspension.

[0250] Referring to the first step in the immunoglobulin identification methods as described above, screening via the antigen-specific binding method may be carried out as follows. The first library of polynucleotides, constructed in a virus vector encoding immunoglobulin subunit polypeptides, is divided into a plurality of pools by the method described above. The virus pools are then used to infect pools of host cells equal to the number of virus pools prepared. In this screening method, it is preferred that the host cells are adherent to a solid substrate. The second library of polynucleotides is also introduced into the host cell pools, and

expression of immunoglobulin molecules or fragments thereof on the surface of the host cells is permitted.

[0251] The host cell pools are then contacted with a desired antigen. Following incubation with the antigen, excess unbound antigen is washed away. Finally the pools of cells are screened for antigen binding. Antigen binding may be detected by a variety of methods. For example, an antigen may be conjugated to an enzyme. Following the removal of unbound antigen, substrate is added, and enzyme reaction products are detected. This method may be enhanced by use of a secondary antibody conjugate, or a streptavidin/biotin system. Such screening methods are well known to those of ordinary skill in the art, and are readily available in kit form from standard vendors. Also, if the antigen is bound to microscopic particles, for example, gold beads, binding of the antigen to the host cells may be detected microscopically. As with the cell signaling methods described above, those pools of host cells in which antigen binding is detected are harvested, and the polynucleotides of the first library contained therein are recovered. Alternatively, pools of host cells in which antigen-binding is detected are identified, and polynucleotides of the first library contained therein are recovered from a replicate aliquot of that pool of polynucleotides set aside following initial expansion of the library.

[0252] To further enrich for polynucleotides of the first library which encode antigen-specific immunoglobulin subunit polypeptides, the polynucleotides recovered above are divided into a plurality of sub-pools. The sub-pools are set to contain fewer different members than the pools utilized in the first round. For example, if each of the first pools contained 10^3 different polynucleotides, the sub-pools are set up so as to contain, on average, about 10 or 100 different polynucleotides each. The sub-pools are introduced into host cells with the second library as above, and expression of immunoglobulin molecules, or fragments thereof, on the membrane surface of the host cells is permitted. The host cells are then contacted with antigen as above, and those sub-pools of host cells in which antigen binding is detected are harvested or simply identified, and the polynucleotides of the first library contained therein, or in a replicate aliquot,

are recovered. It will be appreciated by those of ordinary skill in the art that this process may be repeated one or more additional times in order to adequately enrich for polynucleotides encoding antigen-specific immunoglobulin subunit polypeptide.

[0253] Upon further selection and enrichment steps for polynucleotides of the first library, and isolation of those polynucleotides, a similar process is carried out to recover polynucleotides of the second library which, as part of an immunoglobulin molecule, or antigen-specific fragment thereof, bind the desired specific antigen.

[0254] Any host cell capable of expressing immunoglobulin molecules on its surface may be used in this method. Preferred host cells include immunoglobulin-negative plasmacytoma cells, *e.g.*, NS1 cells, Sp2/0 cells, or P3 cells, and early B-cell lymphoma cells.

[0255] An antigen of interest may be contacted with host cells by any convenient method when practicing the direct and indirect antigen-induced cell death methods as described herein. For example, in certain embodiments, antigen, for example a peptide or a polypeptide, is attached to a solid substrate. As used herein, a "solid support" or a "solid substrate" is any support capable of binding a cell or antigen, which may be in any of various forms, as is known in the art. Well-known supports include tissue culture plastic, glass, polystyrene, polypropylene, polyethylene, dextran, nylon, amylases, natural and modified celluloses, polyacrylamides, gabbros, and magnetite. The nature of the carrier can be either soluble to some extent or insoluble for the purposes of the present invention. The support material may have virtually any possible structural configuration as long as the coupled molecule is capable of binding to a cell. Thus, the support configuration may be spherical, as in a bead, or cylindrical, as in the inside surface of a test tube, or the external surface of a rod. Alternatively, the surface may be flat such as a sheet, test strip, etc. Preferred supports include polystyrene beads. The support configuration may include a tube, bead, microbead, well, plate, tissue culture plate, petri plate, microplate, microtiter plate, flask, stick, strip, vial, paddle, etc., etc. A solid support may be magnetic

or non-magnetic. Those skilled in the art will know many other suitable carriers for binding cells or antigens, or will be able to readily ascertain the same.

[0256] Alternatively, an antigen is expressed on the surface of an antigen-expressing presenting cell. As used herein an "antigen-expressing presenting cell" refers to a cell which expresses an antigen of interest on its surface in a manner such that the antigen may interact with immunoglobulin molecules attached to the surface of host cells of the present invention. An preferred antigen-expressing presenting cell is engineered such that it expresses the antigen of interest as a recombinant protein, but the antigen may be a native antigen of that cell. Recombinant antigen-expressing presenting cells may be constructed by any suitable method using molecular biology and protein expression techniques well-known to those of ordinary skill in the art. Typically, a plasmid vector which encodes the antigen of interest is transfected into a suitable cell, and the cell is screened for expression of the desired polypeptide antigen. Preferred recombinant antigen-expressing presenting cells stably express the antigen of interest. A cell of the same type as the antigen-expressing presenting cell except that it has not been engineered to express the antigen of interest is referred to herein as an "antigen-free presenting cell." Any suitable cell line may be used to prepare antigen-expressing presenting cells. Examples of cell lines include, but are not limited to: monkey kidney CVI line transformed by SV40 (COS-7, ATCC CRL 165 1); human embryonic kidney line (293, Graham *et al.* *J. Gen Virol.* 36:59 (1977)); baby hamster kidney cells (BHK, ATCC CCL 10); chinese hamster ovary-cells-DHFR (CHO, Urlaub and Chasin, *Proc. Natl. Acad. Sci. (USA)* 77:4216, (1980); mouse sertoli cells (TM4, Mather, *Biol. Reprod.* 23:243-251 (1980)); monkey kidney cells (CVI ATCC CCL 70); african green monkey kidney cells (VERO-76, ATCC CRL-1587); human cervical carcinoma cells (HELA, ATCC CCL 2); canine kidney cells (MDCK, ATCC CCL 34); buffalo rat liver cells (BRL 3A, ATCC CRL 1442); human lung cells (W138, ATCC CCL 75); human liver cells (hep G2, HB 8065); mouse mammary tumor (MMT 060562, ATCC CCL 51); TRI cells (Mather *et al.*, *Annals N. Y. Acad. Sci* 383:44-68 (1982)); NIH/3T3 cells (ATCC CRL-1658); and mouse L cells (ATCC

CCL-1). Additional cell lines will become apparent to those of ordinary skill in the art. A wide variety of cell lines are available from the American Type Culture Collection, 10801 University Boulevard, Manassas, VA 20110-2209.

[0257] As will be appreciated by those of ordinary skill in the art, antigen-expressing presenting cells will comprise many naturally-occurring antigenic determinants on their surface in addition to the antigen of interest. Certain of the host cells of the present invention which express a broad spectrum of different immunoglobulin molecules, or antigen-specific fragments thereof on their surface would be expected to bind to these additional antigenic determinants. Accordingly, when an antigen-expressing presenting cell is used to contact host cells of the invention with the antigen of interest, it is necessary to first deplete the host cell population of those host cells which express immunoglobulins reactive for these additional antigenic determinants. The present invention provides methods to deplete the host cell population of host cells expressing immunoglobulin molecules specific for naturally-occurring surface antigens of the antigen-free presenting cell. This is illustrated in Fig. 5. Essentially, these methods comprise contacting the host cell population with antigen-free presenting cells prior to contacting the population of host cells with antigen-expressing presenting cells.

[0258] In one embodiment, this method comprises adsorbing the population of host cells to antigen-free presenting cells which are bound to a solid substrate. The unbound cells and/or the polynucleotides contained therein are recovered, and the recovered host cells, or new host cells into which the recovered polynucleotides have been introduced, are then contacted with antigen-expressing presenting cells. In those selection methods where pools of host cells are contacted with antigen, the pools of host cells are adsorbed to antigen-free presenting cells bound to a solid substrate. The unbound cells in the pool and/or the polynucleotides contained therein, are recovered, and the recovered host cells, or host cells into which the recovered polynucleotides have been introduced, are then contacted with antigen-expressing presenting cells.

[0259] In another embodiment, the method comprises contacting the population of host cells with antigen-free presenting cells under conditions wherein host cells expressing surface immunoglobulin molecules which react with surface antigens of antigenic determinants on the antigen-free presenting cells undergo either programmed cell death, *e.g.*, apoptosis, direct or indirect cell death, or cell signaling, *i.e.*, expression of a reporter molecule, all as described above, upon cross-linking of immunoglobulin molecules on the surface of the host cells. Those host cells, and more specifically, polynucleotides from either the first library or second library, from those host cells which have not succumbed to cell death or do not express a reporter molecule, are then recovered. For example, if the host cell population expressing immunoglobulin molecules is maintained attached to a solid substrate, and those cells which undergo cell death are released from the substrate, the contents of the culture fluid are removed and discarded, and the cells which remain attached, and the polynucleotides contained therein, are recovered.

[0260] As will be appreciated by those of ordinary skill in the art, depleting the host cell population of those host cells which express immunoglobulins reactive with determinants carried on the antigen-free presenting cells may require more than one round of depletion. It is further contemplated that successive rounds of depletion may be alternated with successive rounds of enrichment for host cells expressing immunoglobulin molecules which specifically bind to the antigen of interest expressed on the antigen-expressing presenting cells.

[0261] In yet another embodiment, a screening method is provided to recover polynucleotides encoding immunoglobulin molecules, or antigen-specific functional fragments thereof, based on a desired antigen-specific function of the immunoglobulin molecule. According to this method, pools of host cells are prepared which express fully-soluble immunoglobulin molecules. Expression is permitted, and the resulting cell medium is tested in various functional assays which require certain desired antigenic specificities. According to this method, the "function" being tested may be a standard effector function carried out by an immunoglobulin molecule, *e.g.*, virus neutralization, opsonization, ADCC,

antagonist/agonist activity, histamine release, hemagglutination, or hemagglutination inhibition. Alternatively, the “function” may simply refer to binding an antigen.

[0262] In a related embodiment, a screening method is provided to select immunoglobulin molecules of a known antigenic specificity, but with altered effector functions. According to these embodiments, libraries of immunoglobulin subunit polypeptides with a known antigenic specificity, but with alterations in constant domain regions known to be involved in a given effector function, are constructed. According to this method, pools of host cells are prepared which express fully-soluble immunoglobulin molecules. Expression is permitted, and the resulting cell medium is tested in various functional assays for improved or suppressed activity. According to this method, the “function” being tested may be a standard effector function carried out by an immunoglobulin molecule, *e.g.*, virus neutralization, opsonization, complement binding, ADCC, antagonist/agonist activity, histamine release, hemagglutination, or hemagglutination inhibition.

[0263] Referring to the first step in the immunoglobulin identification method as described above, the screening for effector function may be carried out as follows. The first library of polynucleotides encoding fully secreted immunoglobulin subunit polypeptides is divided into a plurality of pools, as described above, each pool containing about 10, 100, 10^3 , 10^4 , 10^5 , 10^6 , 10^7 , 10^8 , or 10^9 different polynucleotides encoding fully-secreted immunoglobulin subunit polypeptides with different variable regions. Preferred pools initially contain about 10^3 polynucleotides each. Each pool is expanded and a replicate aliquot is set aside for later recovery. Where the pools of polynucleotides are constructed in virus vectors, preferably poxvirus vectors, and even more preferably vaccinia virus vectors, the pools are prepared, *e.g.*, by diluting a high-titer stock of the virus library and using the portions to infect microcultures of tissue culture cells at a low MOI, *e.g.*, MOI < 0.1. Typically a greater than 1,000 fold expansion in the viral titer is obtained after 48 hrs infection. Expanding viral titers in multiple

individual pools mitigates the risk that a subset of recombinants will be lost due to relatively rapid growth of a competing subset.

[0264] The virus pools are then used to infect pools of host cells equal to the number of virus pools prepared. The number of host cells infected with each pool depends on the number of polynucleotides contained in the pool, and the MOI desired. Virtually any host cell which is permissive for infection with the virus vector used, and which is capable of expressing fully-secreted immunoglobulin molecules may be used in this method. Preferred host cells include immunoglobulin-negative plasmacytoma cells, *e.g.*, NS1 cells, Sp2/0 cells, or P3 cells, and early B-cell lymphoma cells. The cells may be cultured in suspension or attached to a solid surface. The second library of polynucleotides is also introduced into the host cell pools, and expression of fully secreted immunoglobulin molecules or fragments thereof is permitted.

[0265] The conditioned medium in which the host cell pools were cultured is then recovered and tested in a standardized functional assay for effector function in response to a specific target antigen.

[0266] Any suitable functional assay may be used in this method. For example, the harvested cell supernatants may be tested in a virus neutralization assay to detect immunoglobulin molecules with the ability to neutralize a target virus, for example, HIV. Alternatively, the harvested cell supernatants may be tested for the ability to block or facilitate, *i.e.*, act as an antagonist or an agonist of, a target cellular function, for example, apoptosis. Exemplary suitable functional assays are described in the Examples, *infra*. As used herein, a “functional assay” also included simple detection of antigen binding, for example, through use of a standard ELISA assay, which is well known to those of ordinary skill in the art.

[0267] Where the conditioned medium in which a given host cell pool was grown exerts the desired function, the polynucleotides of the first library contained in host cells of that pool are recovered from the aliquot previously set aside following initial expansion of that pool of polynucleotide.

[0268] To further enrich for polynucleotides of the first library which encode antigen-specific immunoglobulin subunit polypeptides, the polynucleotides recovered above are divided into a plurality of sub-pools. The sub-pools are set to contain fewer different members than the pools utilized above. For example, if each of the first pools contained 10^3 different polynucleotides, the sub-pools are set up so as to contain, on average, about 10 or 100 different polynucleotides each. The sub-pools are introduced into host cells with the second library as above, and expression of fully secreted immunoglobulin molecules, or fragments thereof, is permitted. The conditioned medium in which the host cell pools are cultured is recovered and tested in a standardized functional assay for effector function in response to a specific target antigen as described above, conditioned media samples which possess the desired functional characteristic are identified, and the polynucleotides of the first library contained in host cells of that sub-pool are recovered from the aliquot previously set aside as described above. It will be appreciated by those of ordinary skill in the art that this process may be repeated one or more additional times in order to adequately enrich for polynucleotides encoding antigen-specific immunoglobulin subunit polypeptides.

[0269] Upon further selection and enrichment steps for polynucleotides of the first library, and isolation of those polynucleotides, a similar process is carried out to recover polynucleotides of the second library which, as part of an fully secreted immunoglobulin molecule, or fragment thereof, exhibits the desired antigen-specific function.

[0270] Kits. The present invention further provides a kit for the selection of antigen-specific recombinant immunoglobulins expressed in a eukaryotic host cell. The kit comprises one or more containers filled with one or more of the ingredients required to carry out the methods described herein. In one embodiment, the kit comprises: (a) a first library of polynucleotides encoding, through operable association with a transcriptional control region, a plurality of first immunoglobulin subunit polypeptides, where each first immunoglobulin subunit polypeptide comprises (i) a first immunoglobulin constant region selected from the group consisting of a heavy chain constant region and a light

chain constant region, (ii) an immunoglobulin variable region corresponding to said first constant region, and (iii) a signal peptide capable of directing cell surface expression or secretion of said first immunoglobulin subunit polypeptide, wherein said first library is constructed in a eukaryotic virus vector; (b) a second library of polynucleotides encoding, through operable association with a transcriptional control region, a plurality of second immunoglobulin subunit polypeptides, where each comprises: (i) a second immunoglobulin constant region selected from the group consisting of a heavy chain constant region and a light chain constant region, wherein said second immunoglobulin constant region is not the same as the first immunoglobulin constant region, (ii) an immunoglobulin variable region corresponding to said second constant region, and (iii) a signal peptide capable of directing cell surface expression or secretion of said second immunoglobulin subunit polypeptide, where the second immunoglobulin subunit polypeptide is capable of combining with the first immunoglobulin subunit polypeptide to form a surface immunoglobulin molecule, or antigen-specific fragment thereof, attached to the membrane of a host cell, and where the second library is constructed in a eukaryotic virus vector; and (c) a population of host cells capable of expressing said immunoglobulin molecules. In this kit, the first and second libraries are provided both as infectious virus particles and as inactivated virus particles, where the inactivated virus particles are capable of infecting the host cells and allowing expression of the polynucleotides contained therein, but the inactivated viruses do not undergo virus replication. In addition, the host cells provided with the kit are capable of expressing an antigen-specific immunoglobulin molecule which can be selected through interaction with an antigen. Use of the kit is in accordance to the methods described herein. In certain embodiments the kit will include control antigens and reagents to standardize the validate the selection of particular antigens of interest.

[0271] Isolated immunoglobulins. The present invention further provides an isolated antigen-specific immunoglobulin, or fragment thereof, produced by any of the methods disclosed herein. Such isolated immunoglobulins may be useful

as diagnostic or therapeutic reagents. Further provided is a composition comprising an isolated immunoglobulin of the present invention, and a pharmaceutically acceptable carrier.

[0272] The practice of the present invention will employ, unless otherwise indicated, conventional techniques of cell biology, cell culture, molecular biology, transgenic biology, microbiology, recombinant DNA, and immunology, which are within the skill of the art. Such techniques are explained fully in the literature. See, for example, *Molecular Cloning A Laboratory Manual*, 2nd Ed., Sambrook *et al.*, ed., Cold Spring Harbor Laboratory Press: (1989); *Molecular Cloning: A Laboratory Manual*, Sambrook *et al.*, ed., Cold Springs Harbor Laboratory, New York (1992), *DNA Cloning*, Volumes I and II (D. N. Glover ed., 1985); *Oligonucleotide Synthesis* (M. J. Gait ed., 1984); Mullis *et al.* U.S. Pat. No: 4,683,195; *Nucleic Acid Hybridization* (B. D. Hames & S. J. Higgins eds. 1984); *Transcription And Translation* (B. D. Hames & S. J. Higgins eds. 1984); *Culture Of Animal Cells* (R. I. Freshney, Alan R. Liss, Inc., 1987); *Immobilized Cells And Enzymes* (IRL Press, 1986); B. Perbal, *A Practical Guide To Molecular Cloning* (1984); the treatise, *Methods In Enzymology* (Academic Press, Inc., N.Y.); *Gene Transfer Vectors For Mammalian Cells* (J. H. Miller and M. P. Calos eds., 1987, Cold Spring Harbor Laboratory); *Methods In Enzymology*, Vols. 154 and 155 (Wu *et al.* eds.), *Immunochemical Methods In Cell And Molecular Biology* (Mayer and Walker, eds., Academic Press, London, 1987); *Handbook Of Experimental Immunology*, Volumes I-IV (D. M. Weir and C. C. Blackwell, eds., 1986); *Manipulating the Mouse Embryo*, (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1986); and in Ausubel *et al.*, *Current Protocols in Molecular Biology*, John Wiley and Sons, Baltimore, Maryland (1989).

[0273] General principles of antibody engineering are set forth in *Antibody Engineering*, 2nd edition, C.A.K. Borrebaeck, Ed., Oxford Univ. Press (1995). General principles of protein engineering are set forth in *Protein Engineering, A Practical Approach*, Rickwood, D., *et al.*, Eds., IRL Press at Oxford Univ. Press, Oxford, Eng. (1995). General principles of antibodies and antibody-hapten

binding are set forth in: Nisonoff, A., *Molecular Immunology*, 2nd ed., Sinauer Associates, Sunderland, MA (1984); and Steward, M.W., *Antibodies, Their Structure and Function*, Chapman and Hall, New York, NY (1984). Additionally, standard methods in immunology known in the art and not specifically described are generally followed as in *Current Protocols in Immunology*, John Wiley & Sons, New York; Stites *et al.* (eds) , *Basic and Clinical -Immunology* (8th ed.), Appleton & Lange, Norwalk, CT (1994) and Mishell and Shiigi (eds), *Selected Methods in Cellular Immunology*, W.H. Freeman and Co., New York (1980).

- [0274] Standard reference works setting forth general principles of immunology include *Current Protocols in Immunology*, John Wiley & Sons, New York; Klein, J., *Immunology: The Science of Self-Nonself Discrimination*, John Wiley & Sons, New York (1982); Kennett, R., *et al.*, eds., *Monoclonal Antibodies, Hybridoma: A New Dimension in Biological Analyses*, Plenum Press, New York (1980); Campbell, A., "Monoclonal Antibody Technology" in Burden, R., *et al.*, eds., *Laboratory Techniques in Biochemistry and Molecular Biology*, Vol. 13, Elsevier, Amsterdam (1984).

EXAMPLES

EXAMPLE 1

Construction of Human Immunoglobulin Libraries of Diverse Specificity

[0275] Libraries of polynucleotides encoding diverse immunoglobulin subunit polypeptides are produced as follows. Genes for human VH (variable region of heavy chain), VK (variable region of kappa light chain) and VL (variable region of lambda light chains) are amplified by PCR. For each of the three variable gene families, both a recombinant plasmid library and a vaccinia virus library is constructed. The variable region genes are inserted into a p7.5/tk-based transfer/expression plasmid between immunoglobulin leader and constant region sequences of the corresponding heavy chain or light chain. This plasmid is employed to generate the corresponding vaccinia virus recombinants by trimolecular recombination and can also be used directly for high level expression of immunoglobulin chains following transfection into vaccinia virus infected cells. Lymphoma cells are first infected with the vaccinia heavy chain library, followed by transient transfection with a plasmid light chain library. The co-expression of IgM and light chain results in the assembly and surface expression of antibody molecules.

[0276] 1.1 pVHE. An expression vector comprising the human μ membrane immunoglobulin constant region, designated herein as pVHE is constructed as follows. The strategy is depicted in Fig.3. A cDNA coding for the membrane-bound human IgM heavy chain is isolated from bone marrow RNA using SMART™ RACE cDNA Amplification Kit available from Clontech, Palo Alto, CA. The PCR is carried out using the 5' primer (huC μ 5B) 5'-ATTAGGATCCGGTCACCGTC TCCTCAGGG-3' (SEQ ID NO:24), and 3' primer (huC μ 3S) 5'-ATTAGTCGAC TCATTTCACC TTGAACAAGG TGAC-3' (SEQ ID NO:25). The PCR product then is inserted into the pBluescript II/KS at BamHI and Sall sites for site-directed mutagenesis to eliminate two BstEII sites located in the

CH2 and CH4 domains. Nucleotide substitutions are selected that do not alter the amino acids encoded at these sites.

[0277] Plasmid p7.5/tk, produced as described in Zauderer, PCT Publication No. WO 00/028016, and in Example 5, *infra*, is converted into pVHE by the following method. The multiple cloning site (MCS) of p7.5/tk is replaced with a cassette containing the following restriction sites: NotI-NcoI-BssHII-BstEII-SalI to generate p7.5/tk2. This cassette, having the sequence 5'-GCGGCCGCAA ACCATGGAAA GCGCGCATAT GGTCACCAAA AGTCGAC-3', is referred to herein as SEQ ID NO:26. A cassette encoding the signal peptide sequence corresponding to amino acids -19 to-3 of the IgM heavy chain is cloned into p7.5/tk2 between the NcoI and BssHII sites to produce p7.5/tk2L. The BstEII-mutagenized IgM heavy chain, produced as described above, is then cloned into p7.5/tk2L between the BstEII and SalI sites to generate pVHE. Heavy chain variable region (VH) cassettes comprising nucleotides encoding amino acids -4 to 110, produced by PCR as described below, are then cloned between the BssHII and BstEII sites of pVHE to generate a library of polynucleotides encoding membrane-bound heavy chains. Because of the overlap between the μ heavy chain sequence and the restriction enzyme sites selected, this results in expression of contiguous membrane-bound heavy chain immunoglobulin subunit polypeptides in the correct translational reading frame.

[0278] 1.2 pVHEs. An expression vector comprising the human μ secretory immunoglobulin constant region, designated herein as pVHEs is constructed as follows. The strategy is depicted in Fig.8. A cDNA coding for the secretory human IgM heavy chain is isolated from bone marrow RNA using SMART™ RACE cDNA Amplification Kit. The upstream primer huC μ 5B contains an appended BamHI and a BstEII site at the 5' end, followed by amino acids 111-113 of VH and the first amino acid of C μ H1. The downstream primer shuC μ 3S contains the last 6 amino acids of the secreted C μ , followed by a stop codon and a SalI site. These primers have the following sequences:

huC μ 5B: 5'-ATTAGGATCC GGTCACCGTC TCCTCAGGG -3' (SEQ ID NO:27); and

shuC μ 3S: 5'-ATTAGTCGAC TCAGTAGCAG GTGCCAGCTG T -3' (SEQ ID NO:28).

[0279] The PCR product then is inserted into the pBluescript II/KS at BamHI and SalI sites for site-directed mutagenesis to eliminate two BstEII sites located in the CH2 and CH4 domains. Nucleotide substitutions are selected that do not alter the amino acids encoded at these sites.

[0280] Plasmid p7.5/tk2L, produced as in section 1.1, is converted into pVHEs by the following method. The BstEII-mutagenized secretory IgM heavy chain, produced as described above, is then cloned into p7.5/tk2L between the BstEII and SalI sites to generate pVHEs. Heavy chain variable region (VH) cassettes comprising nucleotides encoding amino acids -4 to 110, produced by PCR as described below, are then cloned between the BssHII and BstEII sites of pVHEs to generate a library of polynucleotides encoding secreted heavy chains. Because of the overlap between the μ heavy chain sequence and the restriction enzyme sites selected, this results in expression of contiguous secretory heavy chain immunoglobulin subunit polypeptides in the correct translational reading frame.

[0281] 1.3 pVKE and pVLE. Expression vectors comprising the human κ and λ immunoglobulin light chain constant regions, designated herein as pVKE and pVLE, are constructed as follows. The strategy is depicted in Fig.4.

[0282] (a) Plasmid p7.5/tk is converted into pVKE by the following method. The two XhoI sites and two HindIII sites of p7.5/tk are removed by fill-in ligation, the 3 ApaLI sites (one at the backbone, one at ColE1 ori, and the other at Amp) are removed by standard methods, and the multiple cloning site (MCS) of p7.5/tk is replaced with a cassette containing the following restriction sites: NotI-NcoI-ApaLI-XhoI-HindIII-SalI to generate p7.5/tk3. This cassette, having the sequence 5'-GCGGCCGCCC ATGGATACGT GCACTTGACT CGAGAAGCTT AGTAGTCGAC-3', is referred to herein as SEQ ID NO:29. A cassette encoding the signal peptide sequence corresponding to amino acids -19

to-2 of the kappa light chain is cloned into p7.5/tk3 between the NcoI and ApaLI sites to generate p7.5/tk3L. A cDNA coding for the C κ region is isolated from bone marrow RNA using SMART™ RACE cDNA Amplification Kit as described above, with primers to include an XhoI site at the 5' end of the region encoding amino acids 104-107+C κ , a stop codon, and a SalI site at its 3' end. These primers have the following sequences: huC κ 5: 5'-CAGGACTCGA GATCAAACGA ACTGTGGCTG -3' (SEQ ID NO:30); huC κ 3: 5'-AATATGTCGA CCTAACACTC TCCCCTGTTG AAGCTCTTT-3' (SEQ ID NO:31); and huC κ 3: 5'-AATATGTCGA CCTAACACTC TCCCCTGTTG AAGCTCTT-3' (SEQ ID NO:32). The C κ cassette is then cloned into p7.5/tk3L between the XhoI and SalI sites to generate pVKE. Kappa light chain variable region cassettes (VK) comprising nucleotides encoding amino acids -3 to 105, produced by PCR as described below, are then cloned into pVKE between the ApaLI and XhoI sites. Because of the overlap between the κ light chain sequence and the restriction enzyme sites selected, this results in expression of contiguous κ light chain immunoglobulin subunit polypeptides in the correct translational reading frame.

- [0283] (b) Plasmid p7.5/tk3L is converted into pVLE by the following method. A cDNA coding for the C κ region is isolated from bone marrow RNA using SMART™ RACE cDNA Amplification Kit as described above, with primers to include a HindIII site and the region encoding amino acids 105 to 107 of V λ at its 5' end and a stop codon and a SalI site at its 3' end. These primers have the following sequences: huC λ 5: 5'-ATTTAAGCTT ACCGTCCTAC GAACTGTGGC TGCACCATCT -3' (SEQ ID NO:33); and huC λ 3 (SEQ ID NO:31). The C κ cassette is then cloned into p7.5/tk3L between the HindIII and SalI sites to generate pVLE. Lambda light chain variable region cassettes (VL) comprising nucleotides encoding amino acids -3 to 104, produced by PCR as described below, are then cloned into pVLE between the ApaLI and HindIII sites. Because of the overlap between the λ light chain sequence and the restriction enzyme sites selected, this results in expression of contiguous λ light chain immunoglobulin subunit polypeptides in the correct translational reading frame.

[0284] 1.4 Variable Regions. Heavy chain, kappa light chain, and lambda light chain variable regions are isolated by PCR for cloning in the expression vectors produced as described above, by the following method. RNA isolated from normal human bone marrow pooled from multiple donors (available from Clontech) is used for cDNA synthesis. Aliquots of the cDNA preparations are used in PCR amplifications with primer pairs selected from the following sets of primers: VH/JH, VK/JK or VL/JL. The primers used to amplify variable regions are listed in Tables 1 and 2.

[0285] (a) Heavy chain variable regions. Due to the way the plasmid expression vectors were designed, VH primers, *i.e.*, the forward primer in the pairs used to amplify heavy chain V regions, have the following generic configuration, with the BssHII restriction site in bold:

VH primers: **GCGCGCACTCC**-start of VH FR1 primer.

The primers are designed to include codons encoding the last 4 amino acids in the leader, with the BssHII site coding for amino acids -4 and -3, followed by the VH family-specific FR1 sequence. Tables 1 and 2 lists the sequences of the different family-specific VH primers. Since the last 5 amino acids of the heavy chain variable region, *i.e.*, amino acids 109-113, which are identical among the six human heavy chain J regions, are embedded in plasmid pVHE, JH primers, *i.e.*, the reverse primers used to amplify the heavy chain variable regions, exhibit the following configuration to include a BstEII site, which codes for amino acids 109 and 110 (shown in bold):

JH primers:

-nucleotide sequence for amino acids 103-108 of VH (ending with a **G**)-
GTCACC

Using these sets of primers, the VH PCR products start with the codons coding for amino acids -4 to 110 with BssHII being amino acids -4 and -3, and end at the BstEII site at the codons for amino acids 109 and 110. Upon digestion with the appropriate restriction enzymes, these PCR products are cloned into pVHE digested with BssHII and BstEII.

[0286] In order to achieve amplification of most of the possible rearranged heavy chain variable regions, families of VH and JH primers, as shown in Tables 1 and 2, are used. The VH1, 3, and 4 families account for 44 out of the 51 V regions present in the human genome. The embedding of codons coding for amino acids 109-113 in the expression vector precludes the use of a single common JH primer. However, the 5 JH primers shown in Tables 1 and 2 can be pooled for each VH primer used to reduce the number of PCR reactions required.

[0287] (b) Kappa light chain variable regions. The VK primers, *i.e.*, the forward primer in the pairs used to amplify kappa light chain variable regions, have the following generic configuration, with the ApaLI restriction site in bold:

VK primer: **GTGCACTCC**-start of VK FR1 primer

The VK primers contain codons coding for the last 3 amino acids of the kappa light chain leader with the ApaLI site coding for amino acids -3 and -2, followed by the VK family-specific FR1 sequences. Since the codons encoding the last 4 amino acids of the kappa chain variable region (amino acids 104-107) are embedded in the expression vector pVKE, the JK primers, *i.e.*, the reverse primer in the pairs used to amplify kappa light chain variable regions, exhibit the following configuration:

JK primer:

-nucleotide sequence coding for amino acids 98-103 of VK-**CTCGAG**

The XhoI site (shown in bold) comprises the codons coding for amino acids 104-105 of the kappa light chain variable region. The PCR products encoding kappa light chain variable regions start at the codon for amino acid -3 and end at the codon for amino acid 105, with the ApaLI site comprising the codons for amino acids -3 and -2 and the XhoI site comprising the codons for amino acids 104 and 105. VK1/4 and VK3/6 primers each have two degenerate nucleotide positions. Employing these JK primers (see Tables 1 and 2), JK1, 3 and 4 will have a Val to Leu mutation at amino acid 104, and JK3 will have an Asp to Glu mutation at amino acid 105.

[0288] (c) Lambda light chain variable regions. The VL primers, *i.e.*, the forward primer in the pairs used to amplify lambda light chain variable regions, have the following generic configuration, with the ApaI restriction site in bold:

VL primer: **GTGCACTCC**-start of VL

The ApaI site comprises the codons for amino acids -3 and -2, followed by the VL family-specific FR1 sequences. Since the codons encoding the last 5 amino acids of VL (amino acids 103-107) are embedded in the expression vector pVLE, the JL primers exhibit the following configuration to include a HindIII site (shown in bold) comprising the codons encoding amino acids 103-104:

JL primer: -nucleotide sequence for amino acids 97-102 of VL-AAGCTT

The PCR products encoding lambda light chain variable regions start at the codon for amino acid -3 and end at the codon for amino acid 104 with the ApaI site comprising the codons for amino acids -3 and -2, and HindIII site comprising the codons for amino acids 103 and 104.

Table 1. Oligonucleotide primers for PCR amplification of human immunoglobulin variable regions. Recognition sites for restriction enzymes used in cloning are indicated in bold type. Primer sequences are from 5' to 3'.

VH1 (SEQ ID NO:34)	TTT TGC GCG CAC TCC CAG GTG CAG CTG GTG CAG TCT GG
VH2 (SEQ ID NO:144)	AATA TGC GCG CAC TCC CAG GTC ACC TTG AAG GAG TCT GG
VH3 (SEQ ID NO:35)	TTT TGC GCG CAC TCC GAG GTG CAG CTG GTG GAG TCT GG
VH4 (SEQ ID NO:36)	TTT TGC GCG CAC TCC CAG GTG CAG CTG CAG GAG TCG GG
VH5 (SEQ ID NO:145)	AATA TGC GCG CAC TCC GAG GTG CAG CTG GTG CAG TCT G
JH1 (SEQ ID NO:37)	GAC GGT GAC CAG GGT GCC CTG GCC CCA

JH2 (SEQ ID NO:38)	GAC GGT GAC CAG GGT GCC ACG GCC CCA
JH3 (SEQ ID NO:39)	GAC GGT GAC CAT TGT CCC TTG GCC CCA
JH4/5 (SEQ ID NO:40)	GAC GGT GAC CAG GGT TCC CTG GCC CCA
JH6 (SEQ ID NO:41)	GAC GGT GAC CGT GGT CCC TTG GCC CCA
VK1 (SEQ ID NO:42)	TTT GTG CAC TCC GAC ATC CAG ATG ACC CAG TCT CC
VK2 (SEQ ID NO:43)	TTT GTG CAC TCC GAT GTT GTG ATG ACT CAG TCT CC
VK3 (SEQ ID NO:44)	TTT GTG CAC TCC GAA ATT GTG TTG ACG CAG TCT CC
VK4 (SEQ ID NO:45)	TTT GTG CAC TCC GAC ATC GTG ATG ACC CAG TCT CC
VK5 (SEQ ID NO:46)	TTT GTG CAC TCC GAA ACG ACA CTC ACG CAG TCT CC
VK6 (SEQ ID NO:47)	TTT GTG CAC TCC GAA ATT GTG CTG ACT CAG TCT CC
JK1 (SEQ ID NO:48)	GAT CTC GAG CTT GGT CCC TTG GCC GAA
JK2 (SEQ ID NO:49)	GAT CTC GAG CTT GGT CCC CTG GCC AAA
JK3 (SEQ ID NO:50)	GAT CTC GAG TTT GGT CCC AGG GCC GAA
JK4 (SEQ ID NO:51)	GAT CTC GAG CTT GGT CCC TCC GCC GAA
JK5 (SEQ ID NO:52)	AAT CTC GAG TCG TGT CCC TTG GCC GAA
VL1 (SEQ ID NO:53)	TTT GTG CAC TCC CAG TCT GTG TTG ACG CAG CCG CC

VL2 (SEQ ID NO:54)	TTT GTG CAC TCC CAG TCT GCC CTG ACT CAG CCT GC
VL3A (SEQ ID NO:55)	TTT GTG CAC TCC TCC TAT GTG CTG ACT CAG CCA CC
VL3B (SEQ ID NO:56)	TTT GTG CAC TCC TCT TCT GAG CTG ACT CAG GAC CC
VL4 (SEQ ID NO:57)	TTT GTG CAC TCC CAC GTT ATA CTG ACT CAA CCG CC
VL5 (SEQ ID NO:58)	TTT GTG CAC TCC CAG GCT GTG CTC ACT CAG CCG TC
VL6 (SEQ ID NO:59)	TTT GTG CAC TCC AAT TTT ATG CTG ACT CAG CCC CA
VL7 (SEQ ID NO:60)	TTT GTG CAC TCC CAG GCT GTG GTG ACT CAG GAG CC
JL1 (SEQ ID NO:61)	GGT AAG CTT GGT CCC AGT TCC GAA GAC
JL2/3 (SEQ ID NO:62)	GGT AAG CTT GGT CCC TCC GCC GAA T

Table 2. Oligonucleotide primers for PCR amplification of human immunoglobulin variable regions. Recognition sites for restriction enzymes used in cloning are indicated in bold type. Primer sequences are from 5' to 3'.

VH1a (SEQ ID NO:63)	AATA TGC GCG CAC TCC CAG GTG CAG CTG GTG CAG TCT GG
VH2a (SEQ ID NO:64)	AATA TGC GCG CAC TCC CAG GTC ACC TTG AAG GAG TCT GG
VH3a (SEQ ID NO:65)	AATA TGC GCG CAC TCC GAG GTG CAG CTG GTG GAG TCT GG
VH4a (SEQ ID NO:66)	AATA TGC GCG CAC TCC CAG GTG CAG CTG CAG GAG TCG GG
VH5a (SEQ ID NO:67)	AATA TGC GCG CAC TCC GAG GTG CAG CTG GTG CAG TCT G

JH1a (SEQ ID NO:68)	GA GAC GGT GAC CAG GGT GCC CTG GCC CCA
JH2a (SEQ ID NO:69)	GA GAC GGT GAC CAG GGT GCC ACG GCC CCA
JH3a (SEQ ID NO:70)	GA GAC GGT GAC CAT TGT CCC TTG GCC CCA
JH4/5a (SEQ ID NO:71)	GA GAC GGT GAC CAG GGT TCC CTG GCC CCA
JH6a (SEQ ID NO:72)	GA GAC GGT GAC CGT GGT CCC TTG GCC CCA
VK1a (SEQ ID NO:73)	CAGGA GTG CAC TCC GAC ATC CAG ATG ACC CAG TCT CC
VK2a (SEQ ID NO:74)	CAGGA GTG CAC TCC GAT GTT GTG ATG ACT CAG TCT CC
VK3a (SEQ ID NO:75)	CAGGA GTG CAC TCC GAA ATT GTG TTG ACG CAG TCT CC
VK4a (SEQ ID NO:76)	CAGGA GTG CAC TCC GAC ATC GTG ATG ACC CAG TCT CC
VK5a (SEQ ID NO:77)	CAGGA GTG CAC TCC GAA ACG ACA CTC ACG CAG TCT CC
VK6a (SEQ ID NO:78)	CAGGA GTG CAC TCC GAA ATT GTG CTG ACT CAG TCT CC
JK1a (SEQ ID NO:79)	TT GAT CTC GAG CTT GGT CCC TTG GCC GAA
JK2a (SEQ ID NO:80)	TT GAT CTC GAG CTT GGT CCC CTG GCC AAA
JK3a (SEQ ID NO:81)	TT GAT CTC GAG TTT GGT CCC AGG GCC GAA
JK4a (SEQ ID NO:82)	TT GAT CTC GAG CTT GGT CCC TCC GCC GAA
JK5a (SEQ ID NO:83)	TT AAT CTC GAG TCG TGT CCC TTG GCC GAA

VL1a (SEQ ID NO:84)	CAGAT GTG CAC TCC CAG TCT GTG TTG ACG CAG CCG CC
VL2a (SEQ ID NO:85)	CAGAT GTG CAC TCC CAG TCT GCC CTG ACT CAG CCT GC
VL3Aa (SEQ ID NO:86)	CAGAT GTG CAC TCC TCC TAT GTG CTG ACT CAG CCA CC
VL3Ba (SEQ ID NO:87)	CAGAT GTG CAC TCC TCT TCT GAG CTG ACT CAG GAC CC
VL4a (SEQ ID NO:88)	CAGAT GTG CAC TCC CAC GTT ATA CTG ACT CAA CCG CC
VL5a (SEQ ID NO:89)	CAGAT GTG CAC TCC CAG GCT GTG CTC ACT CAG CCG TC
VL6a (SEQ ID NO:90)	CAGAT GTG CAC TCC AAT TTT ATG CTG ACT CAG CCC CA
VL7a (SEQ ID NO:91)	CAGAT GTG CAC TCC CAG GCT GTG GTG ACT CAG GAG CC
JL1a (SEQ ID NO:92)	AC GGT AAG CTT GGT CCC AGT TCC GAA GAC
JL2/3a (SEQ ID NO:93)	AC GGT AAG CTT GGT CCC TCC GCC GAA TAC

EXAMPLE 2

Strategies for Selection of Human Immunoglobulins Which Bind a Specific Antigen

[0289] Vaccinia virus expression vectors comprising polynucleotides encoding recombinant heavy chain immunoglobulin subunit polypeptides which, in combination with some unidentified light chain, confer specificity for a defined antigen, are selected as follows, and as shown in Fig. 1. Selection of specific immunoglobulin heavy and light chains is accomplished in two phases. First, a library of diverse heavy chains from antibody producing cells of either naïve or immunized donors is constructed in a pox virus based vector by trimolecular recombination (see Example 5) using as a transfer plasmid pVHE, constructed as

described in Example 1, and a similarly diverse library of immunoglobulin light chains is constructed in a plasmid vector such as pVKE and pVLE, constructed as described in Example 1, in which expression of the recombinant gene is regulated by the p7.5 vaccinia promoter. The immunoglobulin heavy chain constant region in the pox virus constructs is designed to retain the transmembrane region that results in expression of immunoglobulin receptor on the surface membrane. Host cells, *e.g.*, early B cell lymphoma cells, are infected with the pox virus heavy chain library at a multiplicity of infection of 1 (MOI=1). Two hours later the infected cells are transfected with the light chain plasmid library under conditions which allow, on average, 10 or more separate light chain plasmids to be taken up and expressed in each cell. Because expression of the recombinant gene in this plasmid is regulated by a vaccinia virus promoter, high levels of the recombinant gene product are expressed in the cytoplasm of vaccinia virus infected cells without a requirement for nuclear integration. Under these conditions a single cell can express multiple antibodies with different light chains associated with the same heavy chains in characteristic H₂L₂ structures in each infected cell.

[0290] 2.1 Direct antigen-induced apoptosis. An early B cell lymphoma host cell is infected with recombinant vaccinia viruses encoding recombinant heavy chain immunoglobulin subunit polypeptides and transfected with plasmids encoding recombinant light chain immunoglobulin subunit polypeptides as described. The host cells respond to crosslinking of antigen-specific immunoglobulin receptors by induction of spontaneous growth inhibition and apoptotic cell death. As outlined in Figure 1, synthesis and assembly of antibody molecules is allowed to proceed for 12 hours or more at which time specific antigen is presented on a synthetic particle or polymer, or on the surface of an antigen expressing cell, in order to crosslink any specific immunoglobulin receptors and induce apoptosis of selected antibody expressing indicator cells. The genomes of recombinant vaccinia viruses extracted from cells in which apoptosis has been induced are enriched for polynucleotides encoding immunoglobulin heavy chain genes that confer the desired specificity.

[0291] 2.2 Indirect antigen-induced cell death. As shown in Fig. 2A (bottom) and Fig. 2B (top), an early B cell lymphoma host cell is transfected with a construct in which the promoter of an apoptosis induced gene, here, a BAX promoter, drives expression of a foreign cytotoxic T cell epitope. The host cells express the CTL epitope in response to crosslinking of antigen-specific immunoglobulin receptors, and these cross-linked cells will undergo a lytic event upon the addition of specific CTL. The stably transfected host cells are then infected with recombinant vaccinia viruses encoding recombinant heavy chain immunoglobulin subunit polypeptides and transfected with plasmids encoding recombinant light chain immunoglobulin subunit polypeptides as described. As outlined in Figure 1, synthesis and assembly of antibody molecules is allowed to proceed for 12 hours or more at which time specific antigen is presented on a synthetic particle or polymer, or on the surface of an antigen expressing cell, in order to cross-link any specific immunoglobulin receptors. Upon addition of epitope-specific CTL, those cells in which surface immunoglobulin molecules are cross linked undergo a lytic event, thereby indirectly inducing cell death.

[0292] 2.3 Direct antigen-induced cell death. As shown in Fig. 2A (top) and Fig. 2B (bottom), an early B cell lymphoma host cell is transfected with a construct in which the promoter of an apoptosis induced gene, here, a BAX promoter, drives expression of the cytotoxic A subunit of diphtheria toxin. The host cells express the toxin subunit in response to cross linking of antigen-specific immunoglobulin receptors, and these cross-linked cells will succumb to cell death. The stably transfected host cells are then infected with recombinant vaccinia viruses encoding recombinant heavy chain immunoglobulin subunit polypeptides and transfected with plasmids encoding recombinant light chain immunoglobulin subunit polypeptides as described. As outlined in Figure 1, synthesis and assembly of antibody molecules is allowed to proceed for 12 hours or more at which time specific antigen is presented on a synthetic particle or polymer, or on the surface of an antigen expressing cell, in order to cross-link any specific immunoglobulin receptors. Those cells in which surface

immunoglobulin molecules are cross linked rapidly and directly succumb to cell death.

[0293] 2.4 Discussion. The reason expression of these recombinant genes is upregulated by crosslinking surface Ig receptors is that expression of each of the two constructs is regulated by the promoter for a gene whose expression is naturally upregulated in early B cell lymphoma cells following Ig crosslinking. This is illustrated by use of the BAX promoter. BAX being an example of a proapoptotic gene that is normally upregulated in early B cell lymphoma cells under these conditions. Regulatory regions (the “promoter”) for other genes may serve equally well or better. Such genes are identified, for example, by comparing the gene expression profile of early B cell lymphoma cells on microarrays before and after crosslinking of membrane Ig.

[0294] Cells are transfected with a construct leading to expression of the diphtheria A chain (dipA), undergo more rapid apoptosis than is induced by Ig crosslinking alone. An even more rapid cell death is induced by addition of cytotoxic T cells specific for some target peptide that associates with a native MHC molecule expressed in that cell and that is encoded by a minigene whose expression is regulated by a BAX or BAX-like promoter. In addition, host cells other than early B cell lymphoma cells are likewise engineered to express genes which either directly or indirectly induce cell death upon antigen cross linking of surface immunoglobulin molecules, independent of the programmed apoptosis which occurs in early B cell lymphoma cell lines upon antigen cross linking.

[0295] A variety of substrates are employed to present antigen and cross-link specific membrane immunoglobulin receptors in the above selection process. These include, but are not limited to, magnetic beads, protein coated tissue culture plates, and cells transfected with a gene encoding the target antigen. Examples of cells that may be transfected for efficient expression of the target antigen include, but are not limited to, L cells and NIH 3T3 cells. However, if a transfected cell is employed to express and present a recombinant antigen, then is necessary to first deplete the immunoglobulin-expressing host cell population of any host cells that express antibodies reactive with membrane antigens of the

non-transfected cell. Such depletion could be accomplished in one or more rounds of absorption to non-transfected cells bound to a solid substrate. It would then be possible to employ the antigen expressing transfectant for positive selection of cells expressing specific recombinant antibodies. In a preferred embodiment, alternating cycles of negative and positive selection are repeated as often as necessary to achieve a desired enrichment.

[0296] In one example of a positive selection step, antibody expressing B lymphoma cells are allowed to adhere to a solid substrate to which B cell specific anti-CD19 and/or anti-CD20 antibody has been bound. Adherent indicator cells that undergo a lytic event are induced to release their cytoplasmic contents including any viral immunoglobulin heavy chain recombinants into the culture fluid. Recombinant viruses harvested from cells and cell fragments recovered in the culture fluid are enriched for those recombinant viruses that encode an immunoglobulin heavy chain which confers specificity for the selecting antigen when associated with some as yet unidentified light chains. Additional cycles of antigen driven selection in cells freshly infected with this enriched population of recombinant viruses and subsequently transfected with the same initial population of unselected plasmids encoding diverse light chains leads to further enrichment of the desired heavy chains. Following multiple reiterations of this selection process, a small number of heavy chains are isolated which possess optimal specificity for a defined antigen when associated with some unidentified light chains.

[0297] In order to select light chains that confer the desired specificity in association with the previously selected heavy chains, the entire selection process as described above is repeated by infecting host cells at MOI=1 with a library of diverse light chain recombinants in the vaccinia based vector followed by transfection with a plasmid recombinant for one of the previously selected heavy chains. The optimal light chain partners for that heavy chain are isolated following multiple cycles of antigen driven selection as described above.

[0298] In another preferred embodiment, a similar strategy is implemented by exploiting the binding properties conferred on a cell that expresses specific

antibody on its surface membrane. Instead of employing early B cell lymphomas that undergo apoptosis in response to receptor crosslinking as indicator cells, this strategy, depicted in Figure 5, allows host cells expressing a desired immunoglobulin specificity to be selected by binding to synthetic particles or polymers to which antigen is coupled or to the surface of a specific antigen expressing transfected cell. In this case the indicator cells are chosen for the ability to express high levels of membrane immunoglobulin receptors rather than for an apoptotic response to crosslinking of membrane immunoglobulin receptors. Preferred cell lines include immunoglobulin negative plasmacytomas. Other issues related to the specificity, background and efficiency of the selection process are treated as described above.

EXAMPLE 3

Selection of an Antibody with Defined Specificity from a Library of 10^9 Combinations of Immunoglobulin Heavy and Light Chains

[0299] The affinity of specific antibodies that can be selected from a library is a function of the size of that library. In general, the larger the number of heavy and light chain combinations represented in the library, the greater the likelihood that a high affinity antibody is present and can be selected. Previous work employing phage display methods has suggested that for many antigens a library that includes 10^9 immunoglobulin heavy and light chain combinations is of a sufficient size to select a relatively high affinity specific antibody. In principle, it is possible to construct a library with 10^9 recombinants each of which expresses a unique heavy chain and a unique light chain or a single chain construct with a combining site comprising variable regions of heavy and light chains. The most preferred method, however, is to generate this number of antibody combinations by constructing two libraries of 10^5 immunoglobulin heavy chains and 10^4 immunoglobulin light chains that can be co-expressed in all 10^9 possible combinations. In this example greater diversity is represented in the heavy chain

pool because heavy chains have often been found to make a greater contribution than the associated light chain to a specific antigen combining site.

[0300] 3.1 Heavy Chain Genes. A library of vaccinia recombinants at a titer of approximately 10^6 is constructed from a minimum of 10^5 immunoglobulin heavy chain cDNA transfer plasmid recombinants synthesized by the methods previously described (Example 1) from RNA derived from a pool of 100 bone marrow donors. As described below, this library must be further expanded to a titer of at least 10^9 heavy chain recombinants. A preferred method to expand the library is to infect microcultures of approximately 5×10^4 BSC1 cells with individual pools of 10^3 vaccinia heavy chain recombinants. Typically a greater than 1,000 fold expansion in the viral titer is obtained after 48 hrs infection. Expanding viral titers in multiple individual pools mitigates the risk that a subset of recombinants will be lost due to relatively rapid growth of a competing subset.

[0301] 3.2 Light Chain Genes. A library of vaccinia recombinants at a titer of approximately 10^5 is constructed from a minimum of 10^4 immunoglobulin light chain cDNA transfer plasmid recombinants synthesized from RNA derived from a pool of bone marrow donors as described in Example 1. For use in multiple cycles of heavy chain selection as described below, this library must be further expanded to a titer of 10^{10} to 10^{11} light chain recombinants. A preferred method to expand the library is to infect 100 microcultures of approximately 5×10^4 BSC1 cells with individual pools of 10^3 vaccinia light chain recombinants. Viral recombinants recovered from each of the 100 infected cultures are further expanded as a separate pool to a titer of between 10^8 and 10^9 viral recombinants. It is convenient to label these light chain pools L1 to L100.

[0302] 3.3 Selection of Immunoglobulin Heavy Chain Recombinants. 100 cultures of 10^7 cells of a non-producing myeloma, preferably Sp2/0, or early B cell lymphoma, preferably CH33, are infected with viable vaccinia heavy chain recombinants at MOI=1 and simultaneously with psoralen (4'-aminomethyl-Trioxsalen) inactivated vaccinia light chain recombinants at MOI=1 to 10 (see below). For psoralen inactivation, cell-free virus at 10^8 to 10^9 pfu/ml is treated with 10 μ g/ml psoralen for 10 minutes at 25°C and then exposed to long-wave

(365-nm) UV light for 2 minutes (Tsung, K., J.H. Yim, W. Marti, R.M.L. Buller, and J.A. Norton. *J. Virol.* 70:165-171 (1996)) The psoralen treated virus is unable to replicate but allows expression of early viral genes including recombinant genes under the control of early but not late viral promoters. Under these conditions, light chains synthesized from psoralen treated recombinants will be assembled into immunoglobulin molecules in association with the single heavy chain that is, on average, expressed in each infected cell.

[0303] The choice of infection with psoralen inactivated light chain recombinants at MOI=1 or at MOI=10 will influence the relative concentration in a single positive cell of a particular H+L chain combination which will be high at MOI=1 and low (because of dilution by multiple light chains) at MOI=10. A low concentration and correspondingly reduced density of specific immunoglobulin at the cell surface is expected to select for antibodies with higher affinity for the ligand of interest. On the other hand, a high concentration of specific receptor is expected to facilitate binding or signaling through the immunoglobulin receptor.

[0304] Following a first cycle of antigen-specific selection by binding or signaling as described in Example 2, an enriched population of recombinant virus is recovered from each culture with a titer which, during this initial selection and depending on background levels of non-specific binding or spontaneous release of virus, may be between 1% and 10% of the titer of input virus. It is convenient to label as H1a to H100a the heavy chain recombinant pools recovered from cultures in the first cycle of selection that received psoralen treated virus from the original light chain recombinant pools L1 to L100 respectively.

[0305] To carry out a second cycle of selection under the same conditions as the first cycle, it is again necessary to expand the titer of recovered heavy chain recombinants by 10 to 100 fold. For the second cycle of selection non-producing myeloma or early B cell lymphoma are again infected with viable viral heavy chain recombinants and psoralen treated light chain recombinants such that, for example, the same culture of 10^7 cells is infected with heavy chain recombinants recovered in pool H37a and psoralen treated light chain recombinants from the original L37 pool employed to select H37a. Heavy chain recombinants recovered

from the H37a pool in the second cycle of selection are conveniently labeled H37b and so on.

[0306] Following the second cycle of selection, specific viral recombinants are likely, in general, to be enriched by a factor of 10 or more relative to the initial virus population. In this case, it is not necessary for the third cycle of selection to be carried out under the same conditions as the first or second cycle since specific clones are likely to be well-represented even at a 10 fold lower titer. For the third cycle of selection, therefore, 100 cultures of only 10^6 non-producing myeloma or early B cell lymphoma are again infected with viable viral heavy chain recombinants and psoralen treated light chain recombinants from cognate pools. Another reduction by a factor of 10 in the number of infected cells is effected after the 5th cycle of selection.

[0307] 3.4 Identification of Antigen-specific Heavy Chain Recombinants.

[0308] (a) Following any given cycle of selection it is possible to determine whether antigen-specific heavy chains have been enriched to a level of 10% or more in a particular pool, for example H37f, by picking 10 individual viral pfu from that heavy chain pool to test for antigen-specificity in association with light chains of the original L37 pool. Since the light chain population comprises 10^4 diverse cDNA distributed among 100 individual pools, the average pool has approximately 10^2 different light chains. Even if a selected heavy chain confers a desired antigenic specificity only in association with a single type of light chain in the available light chain pool, 1% of cells infected with the selected heavy chain recombinant and the random light chain pool at MOI=1 will express the desired specificity. This frequency can be increased to 10% on average if cells are infected with light chains at MOI=10. A preferred method to confirm specificity is to infect with immunoglobulin heavy chain and a pool of light chains a line of CH33 early B cell lymphoma transfected with an easily detected reporter construct, for example luciferase, driven by the promoter for BAX or another CH33 gene that is activated as a result of membrane receptor crosslinking. Infection of this transfectant with the plaque purified heavy chain recombinant and the relevant light chain pool will result in an easily detected

signal if the selected heavy chain confers the desired antigenic specificity in association with any of the 100 or more light chains represented in that pool. Note that this same method is applicable to analysis of heavy chains whether they are selected by specific-binding or by specific-signaling through immunoglobulin receptors of infected cells.

[0309] (b) An alternative method to identify the most promising antigen-specific heavy chains is to screen for those that are most highly represented in the selected population. Inserts can be isolated by PCR amplification with vector specific primers flanking the insertion site and these inserts can be sequenced to determine the frequency of any observed sequence. In this case, however, it remains necessary to identify a relevant light chain as described below.

[0310] 3.5 Selection of Immunoglobulin Light Chain Recombinants. Once an antigen-specific heavy chain has been isolated, a light chain that confers antigen-specificity in association with that heavy chain can be isolated from the pool that was employed to select that heavy chain as described in 3.4(a). Alternatively, it may be possible to select yet another light chain from a larger library that, in association with the same heavy chain, could further enhance affinity. For this purpose a library of vaccinia recombinants at a titer of approximately 10^6 is constructed from a minimum of 10^5 immunoglobulin light chain cDNA transfer plasmid recombinants synthesized by the methods previously described (Example 1). The procedure described in 3.3 is reversed such that non-producing myeloma or early B cell lymphoma are now infected with viable viral light chain recombinants at $\text{MOI}=1$ and a single selected psoralen treated specific heavy chain recombinant. To promote selection of higher affinity immunoglobulin, it may be preferable to dilute the concentration of each specific H+L chain pair by infection with light chains at $\text{MOI}=10$.

[0311] 3.6 Selection of Immunoglobulin Heavy Chain Recombinants in the Presence of a Single Immunoglobulin Light Chain. The selection of an immunoglobulin heavy chain that can contribute to a particular antibody specificity is simplified if a candidate light chain has already been identified. This may be the case if, for example a murine monoclonal antibody has been

previously selected. The murine light chain variable region can be grafted to a human light chain constant region to optimize pairing with human heavy chains, a process previously described by others employing phage display methods as "Guided Selection" (Jespers, L.S., A. Roberts, S.M. Mahler, G. Winter, H.R. and Hoogenboom. *Bio/Technology* 12:899-903, 1994; Figini, M., L. Obici, D. Mezzanzanica, A. Griffiths, M.I. Colnaghi, G. Winters, and S. Canevari. *Cancer Res.* 58:991-996, 1998). This molecular matching can, in principle, be taken even further if human variable gene framework regions are also grafted into the murine light chain variable region sequence (Rader, C., D.A. Cheresch, and C.F. Barbas III. *Proc. Natl. Acad. Sci. USA* 95:8910-8915). Any human heavy chains selected to pair with this modified antigen-specific light chain can themselves become the basis for selection of an optimal human light chain from a more diverse pool as described in 3.5.

EXAMPLE 4

Selection of Specific Human Antibodies from a cDNA Library constructed in Adenovirus, Herpesvirus, or Retrovirus vectors

- [0312] 4.1 Herpesvirus. A method has been described for the generation of helper virus free stocks of recombinant, infectious Herpes Simplex Virus Amplicons (T.A. Stavropoulos, C.A. Strathdee. 1998 *J. Virology* 72:7137-7143). It is possible that a cDNA Library of human Immunoglobulin Heavy and/or Light chain genes or fragments thereof, including single chain fragments, constructed in the plasmid Amplicon vector could be packaged into a library of infectious amplicon particles using this method. An Amplicon library constructed using immunoglobulin heavy chain genes, and another Amplicon library constructed using immunoglobulin light chain genes could be used to coinfect a non-producing myeloma cell line. The myeloma cells expressing an immunoglobulin gene combination with the desired specificity can be enriched by selection for binding to the antigen of interest. The Herpes Amplicons are capable of stable transgene expression in infected cells. Cells selected for binding in a first cycle will retain their immunoglobulin gene combination, and will stably express

antibody with this specificity. This allows for the reiteration of selection cycles until immunoglobulin genes with the desired specificity can be isolated. Selection strategies that result in cell death could also be attempted. The amplicon vector recovered from these dead selected cells cannot be used to infect fresh target cells, because in the absence of helper virus the amplicons are replication defective and will not be packaged into infectious form. The amplicon vectors contain a plasmid origin of replication and an antibiotic resistance gene. This makes it possible to recover the selected amplicon vector by transforming DNA purified from the selected cells into bacteria. Selection with the appropriate antibiotic would allow for the isolation of bacterial cells that had been transformed by the amplicon vector. The use of different antibiotic resistance genes on the heavy and light chain Amplicon vectors, for example ampicillin and kanamycin, would allow for the separate selection of heavy and light chain genes from the same population of selected cells. Amplicon plasmid DNA can be extracted from the bacteria and packaged into infectious viral particles by cotransfection of the amplicon DNA and packaging defective HSV genomic DNA into packaging cells. Infectious amplicon particles can then be harvested and used to infect a fresh population of target cells for another round of selection

- [0313] 4.2 Adenovirus. Methods have been described for the production of recombinant Adenovirus (S. Miyake, M. Makimura, Y. Kanegae, S. Harada, Y. Sato, K. Takamori, C. Tokuda, I. Saito. 1996 *Proc. Natl. Acad. Sci. USA* **93**: 1320-1324; T.C. He, S. Zhou, L.T. Da Costa, J. Yu, K.W. Kinzler, B. Vogelstein. 1998 *Proc. Natl. Acad. Sci. USA* **95**: 2509-2514) It is possible that a cDNA library could be constructed in an Adenovirus vector using either of these methods. Insertion of cDNA into the E3 or E4 region of Adenovirus results in a replication competent recombinant virus. This library could be used for similar applications as the vaccinia cDNA libraries constructed by trimolecular recombination. For example a heavy chain cDNA library can be inserted into the E3 or E4 region of Adenovirus. This results in a replication competent heavy chain library. A light chain cDNA library could be inserted into the E1 gene of Adenovirus, generating a replication defective library. This replication defective

light chain library can be amplified by infection of cells that provide Adenovirus E1 in trans, such as 293 cells. These two libraries can be used in similar selection strategies as those described using replication competent vaccinia heavy chain library and Psoralen inactivated vaccinia light chain library.

[0314] 4.3 Advantages of vaccinia virus. Vaccinia virus possesses several advantages over Herpes or Adenovirus for construction of cDNA Libraries. First, vaccinia virus replicates in the cytoplasm of the host cell, while HSV and Adenovirus replicate in the nucleus. A higher frequency of cDNA recombinant transfer plasmid may be available for recombination in the cytoplasm with vaccinia than is able to translocate into the nucleus for packaging/recombination in HSV or Adenovirus. Second, vaccinia virus, but not Adenovirus or Herpes virus, is able to replicate plasmids in a sequence independent manner (M. Merchlinsky, B. Moss. 1988 *Cancer Cells* 6: 87-93). Vaccinia replication of cDNA recombinant transfer plasmids may result in a higher frequency of recombinant virus being produced. Although we have described the potential construction of cDNA Libraries in Herpes or Adenovirus vectors, it should be emphasized that there has been no reported use of these methods to construct a cDNA Library in either of these viral vectors.

[0315] 4.4 Retrovirus. Construction of cDNA Libraries in replication defective retroviral vectors have been described (T. Kitamura, M. Onishi, S. Kinoshita, A. Shibuya, A. Miyajima, and G.P. Nolan. 1995 *PNAS* 92:9146-9150; I. Whitehead, H. Kirk, and R. Kay. 1995 *Molecular and Cellular Biology* 15:704-710.). Retroviral vectors integrate upon infection of target cells, and have gained widespread use for their ability to efficiently transduce target cells, and for their ability to induce stable transgene expression. A Retroviral cDNA library constructed using immunoglobulin heavy chain genes, and another Retroviral library constructed using immunoglobulin light chain genes could be used to coinfect a non-producing myeloma cell line. The myeloma cells expressing an immunoglobulin gene combination with the desired specificity can be enriched for by selection for binding to the antigen of interest. Cells selected for binding in a first cycle will retain their immunoglobulin gene combination, and will stably

express immunoglobulins with this specificity. This allows for the reiteration of selection cycles until immunoglobulin genes with the desired specificity can be isolated.

EXAMPLE 5

Trimolecular Recombination

[0316] 5.1 Production of an Expression Library. This example describes a tri-molecular recombination method employing modified vaccinia virus vectors and related transfer plasmids that generates close to 100% recombinant vaccinia virus and, for the first time, allows efficient construction of a representative DNA library in vaccinia virus. The trimolecular recombination method is illustrated in FIG. 6.

[0317] 5.2 Construction of the Vectors. The previously described vaccinia virus transfer plasmid pJ/K, a pUC 13 derived plasmid with a vaccinia virus thymidine kinase gene containing an in-frame Not I site (Merchlinsky, M. *et al.*, Virology 190:522-526), was further modified to incorporate a strong vaccinia virus promoter followed by Not I and Apa I restriction sites. Two different vectors, p7.5/tk and pEL/tk, included, respectively, either the 7.5K vaccinia virus promoter or a strong synthetic early/late (E/L) promoter (FIG. 7). The Apa I site was preceded by a strong translational initiation sequence including the ATG codon. This modification was introduced within the vaccinia virus thymidine kinase (*tk*) gene so that it was flanked by regulatory and coding sequences of the viral *tk* gene. The modifications within the *tk* gene of these two new plasmid vectors were transferred by homologous recombination in the flanking *tk* sequences into the genome of the Vaccinia Virus WR strain derived vNotI⁻vector to generate new viral vectors v7.5/tk and vEL/tk. Importantly, following Not I and Apa I restriction endonuclease digestion of these viral vectors, two large viral DNA fragments were isolated each including a separate non-homologous segment of the vaccinia *tk* gene and together comprising all the genes required for assembly of infectious viral particles. Further details regarding the construction

and characterization of these vectors and their alternative use for direct ligation of DNA fragments in vaccinia virus are described in Example 1.

[0318] 5.3 Generation of an Increased Frequency of Vaccinia Virus Recombinants. Standard methods for generation of recombinants in vaccinia virus exploit homologous recombination between a recombinant vaccinia transfer plasmid and the viral genome. Table 3 shows the results of a model experiment in which the frequency of homologous recombination following transfection of a recombinant transfer plasmid into vaccinia virus infected cells was assayed under standard conditions. To facilitate functional assays, a minigene encoding the immunodominant 257-264 peptide epitope of ovalbumin in association with H-2K^b was inserted at the Not I site in the transfer plasmid tk gene. As a result of homologous recombination, the disrupted tk gene is substituted for the wild type viral tk⁺ gene in any recombinant virus. This serves as a marker for recombination since tk⁻ human 143B cells infected with tk⁻ virus are, in contrast to cells infected with wild type tk⁺ virus, resistant to the toxic effect of BrdU. Recombinant virus can be scored by the viral pfu on 143B cells cultured in the presence of 125 mM BrdU.

[0319] The frequency of recombinants derived in this fashion is of the order of 0.1% (Table 3).

Table 3: Generation of Recombinant Vaccinia Virus by Standard Homologous Recombination				
Virus*	DNA	Titer w/o BrdU	Titer w/ BrdU	% Recombinant**
vaccinia	---	4.6×10^7	3.0×10^3	0.006
vaccinia	30 ng pE/Lova	3.7×10^7	3.2×10^4	0.086
vaccinia	300 ng pE/Lova	2.7×10^7	1.5×10^4	0.056

* vaccinia virus strain vNotI

** % Recombinant = (Titer with BrdU/Titer without BrdU) x 100

[0320] This recombination frequency is too low to permit efficient construction of a cDNA library in a vaccinia vector. The following two procedures were used to generate an increased frequency of vaccinia virus recombinants.

[0321] (1) One factor limiting the frequency of viral recombinants generated by homologous recombination following transfection of a plasmid transfer vector into vaccinia virus infected cells is that viral infection is highly efficient whereas plasmid DNA transfection is relatively inefficient. As a result many infected cells do not take up recombinant plasmids and are, therefore, capable of producing only wild type virus. In order to reduce this dilution of recombinant efficiency, a mixture of naked viral DNA and recombinant plasmid DNA was transfected into Fowl Pox Virus (FPV) infected mammalian cells. As previously described by others (Scheifflinger, F., *et al.*, 1992, Proc. Natl. Acad. Sci. USA 89:9977-9981), FPV does not replicate in mammalian cells but provides necessary helper functions required for packaging mature vaccinia virus particles in cells transfected with non-infectious naked vaccinia DNA. This modification of the homologous recombination technique alone increased the frequency of viral recombinants approximately 35 fold to 3.5% (Table 4).

Table 4: Generation of Recombinant Vaccinia Virus
by Modified Homologous Recombination

Virus	DNA	Titer w/o BrdU	Titer w/ BrdU	% Recombinant*
PFV	None	0	0	0
None	vaccinia WR	0	0	0
PFV	vaccinia WR	8.9×10^6	2.0×10^2	0.002
PFV	vaccinia WR + pE/Lova (1:1)	5.3×10^6	1.2×10^5	2.264
PFV	vaccinia WR + pE/Lova (1:10)	8.4×10^5	3.0×10^4	3.571

* % Recombinant = (Titer with BrdU/Titer without BrdU) x 100

[0322] Table 4. Confluent monolayers of BSC1 cells (5×10^5 cells/well) were infected with $\text{moi}=1.0$ of fowlpox virus strain HP1. Two hours later supernatant was removed, cells were washed 2X with Opti-Mem I media, and transfected using lipofectamine with 600ng vaccinia strain WR genomic DNA either alone, or with 1:1 or 1:10 (vaccinia:plasmid) molar ratios of plasmid pE/Lova. This plasmid contains a fragment of the ovalbumin cDNA, which encodes the SIINFEKL epitope, known to bind with high affinity to the mouse class I MHC molecule K^b . Expression of this minigene is controlled by a strong, synthetic Early/Late vaccinia promoter. This insert is flanked by vaccinia tk DNA. Three days later cells were harvested, and virus extracted by three cycles of freeze/thaw in dry ice isopropanol/ 37°C water bath. Crude virus stocks were titered by plaque assay on human TK- 143B cells with and without BrdU.

[0323] (2) A further significant increase in the frequency of viral recombinants was obtained by transfection of FPV infected cells with a mixture of recombinant plasmids and the two large approximately 80 kilobases and 100 kilobases fragments of vaccinia virus v7.5/tk DNA produced by digestion with Not I and Apa I restriction endonucleases. Because the Not I and Apa I sites have been introduced into the *tk* gene, each of these large vaccinia DNA arms includes a fragment of the *tk* gene. Since there is no homology between the two *tk* gene fragments, the only way the two vaccinia arms can be linked is by bridging through the homologous tk sequences that flank the inserts in the recombinant transfer plasmid. The results in Table 5 show that >99% of infectious vaccinia virus produced in triply transfected cells is recombinant for a DNA insert as determined by BrdU resistance of infected tk- cells.

Table 5: Generation of 100% Recombinant Vaccinia Virus
Using Tri-Molecular Recombination

Virus	DNA	Titer w/o BrdU	Titer w/ BrdU	% Recombinant*
PFV	Uncut v7.5/tk	2.5×10^6	6.0×10^3	0.24
PFV	NotI/ApaI v7.5/tk arms	2.0×10^2	0	0
PFV	NotI/ApaI v7.5/tk arms + pE/Lova (1:1)	6.8×10^4	7.4×10^4	100

* % Recombinant = (Titer with BrdU/Titer without BrdU) x 100

[0324] Table 5. Genomic DNA from vaccinia strain V7.5/tk (1.2 micrograms) was digested with ApaI and NotI restriction endonucleases. The digested DNA was divided in half. One of the pools was mixed with a 1:1 (vaccinia:plasmid) molar ratio of pE/Lova. This plasmid contains a fragment of the ovalbumin cDNA, which encodes the SIINFEKL epitope, known to bind with high affinity to the mouse class I MHC molecule K^b. Expression of this minigene is controlled by a strong, synthetic Early/Late vaccinia promoter. This insert is flanked by vaccinia tk DNA. DNA was transfected using lipofectamine into confluent monolayers (5×10^5 cells/well) of BSC1 cells, which had been infected 2 hours previously with moi=1.0 FPV. One sample was transfected with 600ng untreated genomic V7.5/tk DNA. Three days later cells were harvested, and the virus was extracted by three cycles of freeze/thaw in dry ice isopropanol/ 37⁰ C water bath. Crude viral stocks were plaqued on TK- 143 B cells with and without BrdU selection.

[0325] 5.4 Construction of a Representative cDNA Library in Vaccinia Virus. A cDNA library is constructed in the vaccinia vector to demonstrate representative expression of known cellular mRNA sequences. Additional modifications have been introduced into the p7.5/tk transfer plasmid and v7.5/tk viral vector to enhance the efficiency of recombinant expression in infected cells. These include introduction of translation initiation sites in three different reading

frames and of both translational and transcriptional stop signals as well as additional restriction sites for DNA insertion.

[0326] First, the HindIII J fragment (vaccinia tk gene) of p7.5/tk was subcloned from this plasmid into the HindIII site of pBS phagemid (Stratagene) creating pBS.Vtk.

[0327] Second, a portion of the original multiple cloning site of pBS.Vtk was removed by digesting the plasmid with SmaI and PstI, treating with Mung Bean Nuclease, and ligating back to itself, generating pBS.Vtk.MCS-. This treatment removed the unique SmaI, BamHI, SalI, and PstI sites from pBS.Vtk.

[0328] Third, the object at this point was to introduce a new multiple cloning site downstream of the 7.5k promoter in pBS.Vtk.MCS-. The new multiple cloning site was generated by PCR using 4 different upstream primers, and a common downstream primer. Together, these 4 PCR products would contain either no ATG start codon, or an ATG start codon in each of the three possible reading frames. In addition, each PCR product contains at its 3 prime end, translation stop codons in all three reading frames, and a vaccinia virus transcription double stop signal. These 4 PCR products were ligated separately into the NotI/ ApaI sites of pBS.Vtk.MCS-, generating the 4 vectors, p7.5/ATG0/tk, p7.5/ATG1/tk, p7.5/ATG2/tk, and p7.5/ATG3/tk whose sequence modifications relative to the p7.5/tk vector are shown in Fig. 12. Each vector includes unique BamHI, SmaI, PstI, and SalI sites for cloning DNA inserts that employ either their own endogenous translation initiation site (in vector p7.5/ATG0/tk) or make use of a vector translation initiation site in any one of the three possible reading frames (p7.5/ATG1/tk, p7.5/ATG3/tk, and p7.5/ATG4/tk).

[0329] In a model experiment cDNA was synthesized from poly-A+ mRNA of a murine tumor cell line (BCA39) and ligated into each of the four modified p7.5/tk transfer plasmids. The transfer plasmid is amplified by passage through procaryotic host cells such as *E. coli* as described herein or as otherwise known in the art. Twenty micrograms of Not I and Apa I digested v/tk vaccinia virus DNA arms and an equimolar mixture of the four recombinant plasmid cDNA libraries was transfected into FPV helper virus infected BSC-1 cells for tri-

molecular recombination. The virus harvested had a total titer of 6×10^6 pfu of which greater than 90% were BrdU resistant.

[0330] In order to characterize the size distribution of cDNA inserts in the recombinant vaccinia library, individual isolated plaques were picked using a sterile pasteur pipette and transferred to 1.5ml tubes containing 100 μ l Phosphate Buffered Saline (PBS). Virus was released from the cells by three cycles of freeze/thaw in dry ice/isopropanol and in a 37° C water bath. Approximately one third of each virus plaque was used to infect one well of a 12 well plate containing tk- human 143B cells in 250 μ l final volume . At the end of the two hour infection period each well was overlayed with 1 ml DMEM with 2.5% fetal bovine serum (DMEM-2.5) and with BUdR sufficient to bring the final concentration to 125 μ g/ml. Cells were incubated in a CO₂ incubator at 37°C for three days. On the third day the cells were harvested, pelleted by centrifugation, and resuspended in 500 μ l PBS. Virus was released from the cells by three cycles of freeze/ thaw as described above. Twenty percent of each virus stock was used to infect a confluent monolayer of BSC-1 cells in a 50mm tissue culture dish in a final volume of 3 ml DMEM-2.5. At the end of the two hour infection period the cells were overlayed with 3 ml of DMEM-2.5. Cells were incubated in a CO₂ incubator at 37°C for three days. On the third day the cells were harvested, pelleted by centrifugation, and resuspended in 300 μ l PBS. Virus was released from the cells by three cycles of freeze/ thaw as described above. One hundred microliters of crude virus stock was transferred to a 1.5 ml tube, an equal volume of melted 2% low melting point agarose was added, and the virus/agarose mixture was transferred into a pulsed field gel sample block. When the agar worms were solidified they were removed from the sample block and cut into three equal sections. All three sections were transferred to the same 1.5 ml tube, and 250 μ l of 0.5M EDTA, 1% Sarkosyl, 0.5mg/ml Proteinase K was added. The worms were incubated in this solution at 37°C for 24 hours. The worms were washed several times in 500 μ l 0.5X TBE buffer, and one section of each worm was transferred to a well of a 1% low melting point agarose gel. After the worms were added the wells were sealed by adding additional melted 1% low melting

point agarose. This gel was then electrophoresed in a Bio-Rad pulsed field gel electrophoresis apparatus at 200volts, 8 second pulse times, in 0.5X TBE for 16 hours. The gel was stained in ethidium bromide, and portions of agarose containing vaccinia genomic DNA were excised from the gel and transferred to a 1.5 ml tube. Vaccinia DNA was purified from the agarose using β -Agarase (Gibco) following the recommendations of the manufacturer. Purified vaccinia DNA was resuspended in 50 μ l ddH₂O. One microliter of each DNA stock was used as the template for a Polymerase Chain Reaction (PCR) using vaccinia TK specific primers MM428 and MM430 (which flank the site of insertion) and KlenTaq Polymerase (Clontech) following the recommendations of the manufacturer in a 20 μ l final volume. Reaction conditions included an initial denaturation step at 95°C for 5 minutes, followed by 30 cycles of: 94°C 30 seconds, 55°C 30 seconds, 68°C 3 minutes. Two and a half microliters of each PCR reaction was resolved on a 1% agarose gel, and stained with ethidium bromide. Amplified fragments of diverse sizes were observed. When corrected for flanking vector sequences amplified in PCR the inserts range in size between 300 and 2500 bp.

[0331] Representative expression of gene products in this library was established by demonstrating that the frequency of specific cDNA recombinants in the vaccinia library was indistinguishable from the frequency with which recombinants of the same cDNA occur in a standard plasmid library. This is illustrated in Table 6 for an IAP sequence that was previously shown to be upregulated in murine tumors. Twenty separate pools with an average of either 800 or 200 viral pfu from the vaccinia library were amplified by infecting microcultures of 143B tk- cells in the presence of BDUR. DNA was extracted from each infected culture after three days and assayed by PCR with sequence specific primers for the presence of a previously characterized endogenous retrovirus (IAP, intracisternal A particle) sequence. Poisson analysis of the frequency of positive pools indicates a frequency of one IAP recombinant for approximately every 500 viral pfu (Table 6). Similarly, twenty separate pools with an average of either 1,400 or 275 bacterial cfu from the plasmid library were

amplified by transformation of DH5 a bacteria. Plasmid DNA from each pool was assayed for the presence of the same IAP sequence. Poisson analysis of the frequency of positive pools indicates a frequency of one IAP recombinant for every 450 plasmids (Table 6).

Table 6. Limiting dilution analysis of IAP sequences in a recombinant accinia library and a conventional plasmid cDNA library				
	#Wells Positive by PCR	F_0	μ	Frequency
#PFU/well		Vaccinia Library		
800	18/20	0.05	2.3	1/350
200	6/20	0.7	0.36	1/560
#CFU/well		Plasmid Library		
1400	20/20	0	–	–
275	9/20	0.55	0.6	1/450

F_0 = fraction negative wells; μ = DNA precursors / well = $-\ln F_0$

[0332] Similar analysis was carried out with similar results for representation of an alpha tubulin sequence in the vaccinia library. The comparable frequency of arbitrarily chosen sequences in the two libraries constructed from the same tumor cDNA suggests that although construction of the Vaccinia library is somewhat more complex and is certainly less conventional than construction of a plasmid library, it is equally representative of tumor cDNA sequences.

Discussion

[0333] The above-described tri-molecular recombination strategy yields close to 100% viral recombinants. This is a highly significant improvement over current methods for generating viral recombinants by transfection of a plasmid transfer vector into vaccinia virus infected cells. This latter procedure yields viral recombinants at a frequency of the order of only 0.1%. The high yield of viral recombinants in tri-molecular recombination makes it possible, for the first time,

to efficiently construct genomic or cDNA libraries in a vaccinia virus derived vector. In the first series of experiments a titer of 6×10^6 recombinant virus was obtained following transfection with a mix of 20 micrograms of Not I and Apa I digested vaccinia vector arms together with an equimolar concentration of tumor cell cDNA. This technological advance creates the possibility of new and efficient screening and selection strategies for isolation of specific genomic and cDNA clones.

[0334] The tri-molecular recombination method as herein disclosed may be used with other viruses such as mammalian viruses including vaccinia and herpes viruses. Typically, two viral arms which have no homology are produced. The only way that the viral arms can be linked is by bridging through homologous sequences that flank the insert in a transfer vector such as a plasmid. When the two viral arms and the transfer vector are present in the same cell the only infectious virus produced is recombinant for a DNA insert in the transfer vector.

[0335] Libraries constructed in vaccinia and other mammalian viruses by the tri-molecular recombination method of the present invention may have similar advantages to those described here for vaccinia virus and its use in identifying target antigens in the CTL screening system of the invention. Similar advantages are expected for DNA libraries constructed in vaccinia or other mammalian viruses when carrying out more complex assays in eukaryotic cells. Such assays include but are not limited to screening for DNA encoding receptors and ligands of eukaryotic cells.

EXAMPLE 6

Preparation of Transfer Plasmids

[0336] The transfer vectors may be prepared for cloning by known means. A preferred method involves cutting 1-5 micrograms of vector with the appropriate restriction endonucleases (for example SmaI and SalI or BamHI and SalI) in the appropriate buffers, at the appropriate temperatures for at least 2 hours. Linear digested vector is isolated by electrophoresis of the digested vector through a

0.8% agarose gel. The linear plasmid is excised from the gel and purified from agarose using methods that are well known.

[0337] Ligation. The cDNA and digested transfer vector are ligated together using well known methods. In a preferred method 50-100ng of transfer vector is ligated with varying concentrations of cDNA using T4 DNA Ligase, using the appropriate buffer, at 14°C for 18 to 24 hours.

[0338] Transformation. Aliquots of the ligation reactions are transformed by electroporation into *E. coli* bacteria such as DH10B or DH5 alpha using methods that are well known. The transformation reactions are plated onto LB agar plates containing a selective antibiotic (ampicillin) and grown for 14 – 18 hours at 37°C. All of the transformed bacteria are pooled together, and plasmid DNA is isolated using well known methods.

[0339] Preparation of buffers mentioned in the above description of preferred methods according to the present invention will be evident to those of skill.

EXAMPLE 7

Introduction of Vaccinia Virus DNA Fragments and Transfer Plasmids into Tissue Culture Cells for Trimolecular Recombination

[0340] A cDNA or other library is constructed in the 4 transfer plasmids as described in Example 5, or by other art-known techniques. Trimolecular recombination is employed to transfer this cDNA library into vaccinia virus. Confluent monolayers of BSC1 cells are infected with fowlpox virus HP1 at a moi of 1-1.5. Infection is done in serum free media supplemented with 0.1% Bovine Serum Albumin. The BSC1 cells may be in 12 well or 6 well plates, 60 mm or 100mm tissue culture plates, or 25cm², 75 cm², or 150 cm² flasks. Purified DNA from v7.5/tk or vEL/tk is digested with restriction endonucleases *ApaI* and *NotI*. Following these digestions the enzymes are heat inactivated, and the digested vaccinia arms are purified using a centricon 100 column. Transfection complexes are then formed between the digested vaccinia DNA and

the transfer plasmid cDNA library. A preferred method uses Lipofectamine or Lipofectamine Plus (Life Technologies, Inc.) to form these transfection complexes. Transfections in 12 well plates usually require 0.5 micrograms of digested vaccinia DNA and 10ng to 200 ng of plasmid DNA from the library. Transfection into cells in larger culture vessels requires a proportional increase in the amounts of vaccinia DNA and transfer plasmid. Following a two hour infection at 37°C the fowlpox is removed, and the vaccinia DNA, transfer plasmid transfection complexes are added. The cells are incubated with the transfection complexes for 3 to 5 hours, after which the transfection complexes are removed and replaced with 1 ml DMEM supplemented with 2.5% Fetal Bovine Serum. Cells are incubated in a CO₂ incubated at 37°C for 3 days. After 3 days the cells are harvested, and virus is released by three cycles of freeze/thaw in dry ice/ isopropanol / 37°C water bath.

EXAMPLE 8

Transfection of Mammalian Cells

[0341] This example describes alternative methods to transfect cells with vaccinia DNA and transfer plasmid. Trimolecular recombination can be performed by transfection of digested vaccinia DNA and transfer plasmid into host cells using for example, calcium-phosphate precipitation (F.L. Graham, A.J. Van der Eb (1973) *Virology* 52: 456-467, C. Chen, H. Okayama (1987) *Mol. Cell. Biol.* 7: 2745-2752), DEAE-Dextran (D.J. Sussman, G. Milman (1984) *Mol. Cell. Biol.* 4: 1641-1643), or electroporation (T.K. Wong, E. Neumann (1982) *Biochem. Biophys. Res. Commun.* 107: 584-587, E. Neumann, M. Schafer-Ridder, Y. Wang, P.H. Hofschneider (1982) *EMBO J.* 1: 841-845).

EXAMPLE 9

Construction of MVA Trimolecular Recombination Vectors

[0342] In order to construct a Modified Vaccinia Ankara (MVA) vector suitable for trimolecular recombination, two unique restriction endonuclease sites must be inserted into the MVA tk gene. The complete MVA genome sequence is known (GenBank U94848). A search of this sequence revealed that restriction endonucleases AscI, RsrII, SfiI, and XmaI do not cut the MVA genome. Restriction endonucleases AscI and XmaI have been selected due to the commercial availability of the enzymes, and the size of the recognition sequences, 8 bp and 6 bp for AscI and XmaI respectively. In order to introduce these sites into the MVA tk gene a construct will be made that contains a reporter gene (*E. coli gusA*) flanked by XmaI and AscI sites. The Gus gene is available in pCRII.Gus (M. Merchlinsky, D. Eckert, E. Smith, M. Zauderer. 1997 *Virology* 238: 444-451). This reporter gene construct will be cloned into a transfer plasmid containing vaccinia tk DNA flanks and the early/late 7.5k promoter to control expression of the reporter gene. The Gus gene will be PCR amplified from this construct using Gus specific primers. Gus sense 5' ATGTTACGTCCTGTAGAAACC 3' (SEQ ID NO:94), and Gus Antisense 5'TCATTGTTTGCCTCCCTGCTG 3'(SEQ ID NO:95). The Gus PCR product will then be PCR amplified with Gus specific primers that have been modified to include NotI and XmaI sites on the sense primer, and AscI and ApaI sites on the antisense primer. The sequence of these primers is:

NX-Gus Sense 5' AAAGCGGCCGCCCCGGGATGTTACGTCC 3'
(SEQ ID NO:96); and

AA-Gus antisense 5' AAAGGGCCCGGCGCGCCTCATTGTTTGCC 3'
(SEQ ID NO:97).

[0343] This PCR product will be digested with NotI and ApaI and cloned into the NotI and ApaI sites of p7.5/tk (M. Merchlinsky, D. Eckert, E. Smith, M. Zauderer. 1997 *Virology* 238:444-451). The 7.5k-XmaI-*gusA*-AscI construct will

be introduced into MVA by conventional homologous recombination in permissive QT35 or BHK cells. Recombinant plaques will be selected by staining with the Gus substrate X-Glu (5-bromo-3 indoyl- β -D-glucuronic acid; Clontech) (M.W. Carroll, B. Moss. 1995 *Biotechniques* 19:352-355). MVA-Gus clones, which will also contain the unique XmaI and AscI sites, will be plaque purified to homogeneity. Large scale cultures of MVA-Gus will be amplified on BHK cells, and naked DNA will be isolated from purified virus. After digestion with XmaI and AscI the MVA-Gus DNA can be used for trimolecular recombination in order to construct cDNA expression libraries in MVA.

[0344] MVA is unable to complete its life cycle in most mammalian cells. This attenuation can result in a prolonged period of high levels of expression of recombinant cDNAs, but viable MVA cannot be recovered from infected cells. The inability to recover viable MVA from selected cells would prevent the repeated cycles of selection required to isolate functional cDNA recombinants of interest. A solution to this problem is to infect MVA infected cells with a helper virus that can complement the host range defects of MVA. This helper virus can provide the gene product(s) which MVA lacks that are essential for completion of its life cycle. It is unlikely that another host range restricted helper virus, such as fowlpox, would be able to complement the MVA defect(s), as these viruses are also restricted in mammalian cells. Wild type strains of vaccinia virus would be able to complement MVA. In this case however, production of replication competent vaccinia virus would complicate additional cycles of selection and isolation of recombinant MVA clones. A conditionally defective vaccinia virus could be used which could provide the helper function needed to recover viable MVA from mammalian cells under nonpermissive conditions, without the generation of replication competent virus. The vaccinia D4R open reading frame (orf) encodes a uracil DNA glycosylase enzyme. This enzyme is essential for vaccinia virus replication, is expressed early after infection (before DNA replication), and disruption of this gene is lethal to vaccinia. It has been demonstrated that a stably transfected mammalian cell line expressing the vaccinia D4R gene was able to complement a D4R deficient vaccinia virus (G.

W. Holzer, F.G. Falkner. 1997 *J. Virology* 71:4997-5002). A D4R deficient vaccinia virus would be an excellent candidate as a helper virus to complement MVA in mammalian cells.

[0345] In order to construct a D4R complementing cell line the D4R orf will be cloned from vaccinia strain v7.5/tk by PCR amplification using primers D4R-Sense 5' AAAGGATCCA TAATGAATTC AGTGACTGTA TCACACG 3' (SEQ ID NO:98), and D4R Antisense 5' CTTGCGGCCG CTTAATAAAT AAACCCTTGA GCCC 3'(SEQ ID NO:99). The sense primer has been modified to include a BamHI site, and the anti-sense primer has been modified to include a NotI site. Following PCR amplification and digestion with BamHI and NotI the D4R orf will be cloned into the BamHI and NotI sites of pIRESHyg (Clontech). This mammalian expression vector contains the strong CMV Immediate Early promoter/Enhancer and the ECMV internal ribosome entry site (IRES). The D4RIRESHyg construct will be transfected into BSC1 cells and transfected clones will be selected with hygromycin. The IRES allows for efficient translation of a polycistronic mRNA that contains the D4Rorf at the 5' end, and the Hygromycin phosphotransferase gene at the 3' end. This results in a high frequency of Hygromycin resistant clones being functional (the clones express D4R). BSC1 cells that express D4R (BSC1.D4R) will be able to complement D4R deficient vaccinia, allowing for generation and propagation of this defective strain.

[0346] To construct D4R deficient vaccinia, the D4R orf (position 100732 to 101388 in vaccinia genome) and 983 bp (5' end) and 610 bp (3' end) of flanking sequence will be PCR amplified from the vaccinia genome. Primers D4R Flank sense 5' ATTGAGCTCT TAATACTTTT GTCGGGTAAC AGAG 3' (SEQ ID NO:100), and D4R Flank antisense 5' TTAATCGAGA GTGTCGCAAT TTGGATTTT 3' (SEQ ID NO:101) contain a SacI (Sense) and XhoI (Antisense) site for cloning and will amplify position 99749 to 101998 of the vaccinia genome. This PCR product will be cloned into the SacI and XhoI sites of pBluescript II KS (Stratagene), generating pBS.D4R.Flank. The D4R gene contains a unique EcoRI site beginning at nucleotide position 3 of the 657bp orf,

and a unique PstI site beginning at nucleotide position 433 of the orf. Insertion of a Gus expression cassette into the EcoRI and PstI sites of D4R will remove most of the D4R coding sequence. A 7.5k promoter- Gus expression vector has been constructed (M. Merchlinsky, D. Eckert, E. Smith, M. Zauderer. 1997 *Virology* 238:444-451). The 7.5-Gus expression cassette will be isolated from this vector by PCR using primers 7.5 Gus Sense 5' AAAGAATTCC TTTATTGTCA TCGGCCAAA 3' (SEQ ID NO:102) and 7.5Gus antisense 5' AATCTGCAGT CATTGTTTGC CTCCTGCTG 3' (SEQ ID NO:103). The 7.5Gus sense primer contains an EcoRI site and the 7.5Gus antisense primer contains a PstI site. Following PCR amplification the 7.5Gus molecule will be digested with EcoRI and PstI and inserted into the EcoRI and PstI sites in pBS.D4R.Flank, generating pBS.D4R-/7.5Gus⁺. D4R-/Gus⁺ vaccinia can be generated by conventional homologous recombination by transfecting the pBS.D4R-/7.5Gus⁺ construct into v7.5/tk infected BSC1.D4R cells. D4R-/Gus⁺ virus can be isolated by plaque purification on BSC1.D4R cells and staining with X-Glu. The D4R- virus can be used to complement and rescue the MVA genome in mammalian cells.

- [0347] In a related embodiment, the MVA genome may be rescued in mammalian cells with other defective poxviruses, and also by a psoralen/UV-inactivated wild-type poxviruses. Psoralen/UV inactivation is discussed herein.

EXAMPLE 10

Construction and use of D4R Trimolecular Recombination Vectors

- [0348] Poxvirus infection can have a dramatic inhibitory effect on host cell protein and RNA synthesis. These effects on host gene expression could, under some conditions, interfere with the selection of specific poxvirus recombinants that have a defined physiological effect on the host cell. Some strains of vaccinia virus that are deficient in an essential early gene have been shown to have greatly reduced inhibitory effects on host cell protein synthesis. Production of recombinant cDNA libraries in a poxvirus vector that is deficient in an early gene

function could, therefore, be advantageous for selection of certain recombinants that depend on continued active expression of some host genes for their physiological effect. Disruption of essential viral genes prevents propagation of the mutant strain. Replication defective strains of vaccinia could, however, be rescued by providing the missing function through transcomplementation in host cells or by helper virus that can be induced to express this gene.

[0349] Infection of a cell population with a poxvirus library constructed in a replication deficient strain should greatly attenuate the effects of infection on host cell signal transduction mechanisms, differentiation pathways, and transcriptional regulation. An additional and important benefit of this strategy is that expression of the essential gene under the control of a targeted transcriptional regulatory region can itself be the means of selecting recombinant virus that directly or indirectly lead to activation of that transcriptional regulatory region. Examples include the promoter of a gene activated as a result of crosslinking surface immunoglobulin receptors on early B cell precursors or the promoter of a gene that encodes a marker induced following stem cell differentiation. If such a promoter drives expression of an essential viral gene, then only those viral recombinants that directly or indirectly activate expression of that transcriptional regulator will replicate and be packaged as infectious particles. This method has the potential to give rise to much lower background than selection methods based on expression of *dipA* or a CTL target epitope because uninduced cells will contain no replication competent vaccinia virus that might be released through non-specific bystander effects. The selected recombinants can be further expanded in a complementing cell line or in the presence of a complementing helper virus or transfected plasmid.

[0350] A number of essential early vaccinia genes have been described. Preferably, a vaccinia strain deficient for the D4R gene could be employed. The vaccinia D4R open reading frame (orf) encodes a uracil DNA glycosylase enzyme. This enzyme is required for viral DNA replication and disruption of this gene is lethal to vaccinia (A.K. Millns, M.S. Carpenter, and A.M. Delange. 1994 *Virology* 198:504-513). It has been demonstrated that a stably transfected

mammalian cell line expressing the vaccinia D4R gene is able to complement a D4R deficient vaccinia virus (G. W. Holzer, F.G. Falkner. 1997 *J. Virology* 71: 4997-5002). In the absence of D4R complementation, infection with the D4R deficient vaccinia results in greatly reduced inhibition of host cell protein synthesis (Holzer and Falkner). It has also been shown that a foreign gene inserted into the tk gene of D4R deficient vaccinia continues to be expressed at high levels, even in the absence of D4R complementation (M. Himly, M. Pfeiderer, G. Holzer, U. Fischer, E. Hannak, F.G. Falkner, and F. Dorner. 1998 *Protein Expression and Purification* 14: 317-326). The replication deficient D4R strain is, therefore, well-suited for selection of viral recombinants that depend on continued active expression of some host genes for their physiological effect.

[0351] To implement this strategy for selection of specific recombinants from representative cDNA libraries constructed in a D4R deficient vaccinia strain the following cell lines and vectors are required:

1. D4R expressing complementing cell line is required for expansion of D4R deficient viral stocks.
2. The D4R gene must be deleted or inactivated in a viral strain suitable for trimolecular recombination.
3. Plasmid or viral constructs must be generated that express D4R under the control of different inducible promoters such as that which regulates expression of BAX or other genes induced following crosslinking of membrane immunoglobulin receptors on CH33 B lymphoma cells or the promoter for expression of type X collagen following induction of chondrocyte differentiation from C3H10T1/2 progenitor cells. Stable transfectants of these constructs in the relevant cell line are required to rescue specific recombinants. Alternatively, a helper virus expressing the relevant construct can be employed for inducible expression in either cell lines or primary cultures.

[0352] 10.1 Construction of a D4R Complementing Cell Line A D4R complementing cell line is constructed as follows. First, the D4R orf (position 100732 to 101388 in vaccinia genome) is cloned from vaccinia strain v7.5/tk by PCR amplification using the following primers:

D4R-sense, 5' AAAGAATTCA TAATGAATTC
AGTGACTGTA TCACACG 3', designated
herein as SEQ ID NO:104;

and D4R-antisense: 5' CTTGGATCCT
TAATAAATAA ACCCTTGAGC CC 3',
designated herein as SEQ ID NO:105.

The sense primer is modified to include an EcoRI site, and the anti-sense primer is modified to include a BamHI site (both underlined). Following standard PCR amplification and digestion with EcoRI and BamHI, the resulting D4R orf is cloned into the EcoRI and BamHI sites of pIRESneo (available from Clontech, Palo Alto, CA). This mammalian expression vector contains the strong CMV immediate early promoter/enhancer and the ECMV internal ribosome entry site (IRES). The D4R/IRESneo construct is transfected into BSC1 cells and transfected clones are selected with G418. The IRES allows for efficient translation of a polycistronic mRNA that contains the D4Rorf at the 5' end, and the neomycin phosphotransferase gene at the 3' end. This results in a high frequency of G418 resistant clones being functional (the clones express D4R). Transfected clones are tested by northern blot analysis using the D4R gene as probe in order to identify clones that express high levels of D4R mRNA. BSC1 cells that express D4R (BSC1.D4R) are able to complement D4R deficient vaccinia, allowing for generation and propagation of D4R defective viruses.

[0353] 10.2. Construction of D4R Deficient vaccinia vector A D4R-deficient vaccinia virus, suitable for trimolecular recombination as described in Example 5, *supra*, is constructed by disruption of the D4R orf (position 100732 to 101388 in vaccinia genome) through the insertion of an *E.Coli GusA* expression cassette into a 300-bp deletion, by the following method.

[0354] In order to insert the *GusA* gene, regions flanking the insertion site are amplified from vaccinia virus as follows. The left flanking region is amplified with the following primers:

D4R left flank sense: 5' AATAAGCTTT
ACTCCAGATA ATATGGA 3', designated
herein as SEQ ID NO:106; and

D4R left flank antisense: 5' AATCTGCAGC
CCAGTTCCAT TTT 3', designated herein as
SEQ ID NO:107.

These primers amplify a region extending from position 100167 to position 100960 of the vaccinia genome, and have been modified to include a HindIII (Sense) and PstI (Antisense) site for cloning (both underlined). The resulting PCR product is digested with HindIII and PstI, and cloned into the HindIII and PstI sites of pBS (available from Stratagene), generating pBS.D4R.LF. The right flanking region is amplified with the following primers: D4R right flank sense: 5' AATGGATCCT CATCCAGCGG CTA 3', designated herein as SEQ ID NO:108; and

D4R right flank antisense: 5' AATGAGCTCT
AGTACCTACA ACCCGAA 3', designated
herein as SEQ ID NO:109.

These primers amplify a region extending from position 101271 to position 101975 of the vaccinia genome, and have been modified to include a BamHI (Sense) and SacI (Antisense) site for cloning (both underlined). The resulting PCR product is digested with BamHI and SacI, and cloned into the BamHI and SacI sites of pBS.D4R.LF, creating pBS.D4R.LF/RF.

[0355] An expression cassette comprising the *GusA* coding region operably associated with a poxvirus synthetic early/late (E/L) promoter, is inserted into pBS.D4R.LF/RF by the following method. The E/L promoter- *Gus* cassette is derived from the pEL/tk-*Gus* construct described in Merchlinsky, M., *et al.*, *Virology* 238: 444-451 (1997). The NotI site immediately upstream of the *Gus* ATG start codon is removed by digestion of pEL/tk-*Gus* with NotI, followed by a fill in reaction with Klenow fragment and religation to itself, creating pEL/tk-

Gus(NotI-). The E/L-Gus expression cassette is isolated from pEL/tk-Gus(NotI-) by standard PCR using the following primers:

EL-Gus sense: 5' AAAGTCGACG
GCCAAAATT GAAATTTT 3', designated
herein as SEQ ID NO:110; and

EL-Gus antisense: 5' AATGGATCCT
CATTGTTTGC CTCCC 3', designated herein as
SEQ ID NO:111.

The EL-Gus sense primer contains a SalI site and the EL-Gus antisense primer contains a BamHI site (both underlined). Following PCR amplification the EL-Gus cassette is digested with SalI and BamHI and inserted into the SalI and BamHI sites in pBS.D4R.LF/RF generating pBS.D4R⁻/ELGus. This transfer plasmid contains an EL-Gus expression cassette flanked on both sides by D4R sequence. There is also a 300bp deletion engineered into the D4R orf.

[0356] D4R⁻/Gus⁺ vaccinia viruses suitable for trimolecular recombination are generated by conventional homologous recombination following transfection of the pBS.D4R⁻/ELGus construct into v7.5/tk-infected BSC1.D4R cells. D4R⁻/Gus⁺ virus are isolated by plaque purification on BSC1.D4R cells and staining with X-Glu (M.W. Carroll, B. Moss. 1995. *Biotechniques* 19: 352-355). This new strain is designated v7.5/tk/Gus/D4R.

[0357] DNA purified from v7.5/tk/Gus/D4R is used to construct representative vaccinia cDNA libraries by trimolecular recombination according to the method described in Example 5, except that the reactions are carried out in the BSC1.D4R complementing cell line.

[0358] 10.3. Preparation of host cells expressing D4R under the control of inducible promoters Host cells which express the D4R gene upon induction of an inducible promoter are prepared as follows. Plasmid constructs are generated that express the vaccinia D4R gene under the control of an inducible promoter. Examples of inducible promoters include, but are not limited to, promoters which are upregulated following crosslinking of membrane immunoglobulin on CH33 cells (for antibody selection), *e.g.*, the BAX promoter as described in Examples

2 and 3. The vaccinia D4R orf is amplified by PCR using primers D4R sense and D4R antisense described above in section 10.1. These PCR primers are modified as needed to include desirable restriction endonuclease sites. The D4R orf is then cloned in a suitable eukaryotic expression vector (which allows for the selection of stably transformed cells) in operable association of any desired promoter employing methods known to those skilled in the art.

[0359] The construct is then transfected into a suitable host cell, for example, the for selection of antibodies as described in Examples 2 and 3, the D4R gene, in operable association with the BAX promoter, is stably transfected into a suitable cell line, for example, a CH33 cell line, a CH 31 cell line, or a WEHI-231 cell line. The resulting host cells are utilized in the production of antibodies, essentially as described in Example 3, using libraries prepared in v7.5/tk/Gus/D4R. Antigen-induced cross-linking of membrane-expressed immunoglobulin molecules on the surface of host cells results in the induction of expression of the D4R gene product in the cross-linked cells. Expression of D4R complements the defect in the v7.5/tk/Gus/D4R genomes in which the libraries are produced, allowing the production of infectious virus particles.

EXAMPLE 11

Attenuation of Poxvirus Mediated Host Shut-off by Reversible Inhibitor of DNA Synthesis

[0360] As discussed *infra*, attenuated or defective virus is sometimes desired to reduce cytopathic effects. Cytopathic effects during viral infection might interfere with selection and identification of immunoglobulin molecules using methods which take advantage of host cell death (*e.g.* apoptosis induced by cross-linking). Such effects can be attenuated with a reversible inhibitor of DNA synthesis such as hydroxyurea (HU) (Pogo, B.G. and S. Dales Virology, 1971. 43(1):144-51). HU inhibits both cell and viral DNA synthesis by depriving replication complexes of deoxyribonucleotide precursors (Hendricks, S.P. and C.K. Mathews J Biol Chem, 1998. 273(45):29519-23). Inhibition of viral DNA

replication blocks late viral RNA transcription while allowing transcription and translation of genes under the control of early vaccinia promoters (Nagaya, A., B.G. Pogo, and S. Dales Virology, 1970. 40(4):1039-51). Thus, treatment with reversible inhibitor of DNA synthesis such as HU allows the detection of effects of cross-linking. Following appropriate incubation, HU inhibition can be reversed by washing the host cells so that the viral replication cycle continues and infectious recombinants can be recovered (Pogo, B.G. and S. Dales Virology, 1971. 43(1):144-51).

[0361] The results in Figure 9 demonstrate that induction of type X collagen synthesis, a marker of chondrocyte differentiation, in C3H10T $\frac{1}{2}$ progenitor cells treated with BMP-2 (Bone Morphogenetic Protein-2) is blocked by vaccinia infection but that its synthesis can be rescued by HU mediated inhibition of viral DNA synthesis. When HU is removed from cultures by washing with fresh medium, viral DNA synthesis and assembly of infectious particles proceeds rapidly so that infectious viral particles can be isolated as soon as 2 hrs post-wash.

[0362] C3H10T $\frac{1}{2}$ cells were infected with WR vaccinia virus at MOI=1 and 1 hour later either medium or 400 ng/ml of BMP-2 in the presence or absence of 2 mM HU was added. After a further 21 hour incubation at 37°C, HU was removed by washing with fresh medium. The infectious cycle was allowed to continue for another 2 hours to allow for initiation of viral DNA replication and assembly of infectious particles. At 24 hours RNA was extracted from cells maintained under the 4 different culture conditions. Northern analysis was carried out using a type X collagen specific probe. The uninduced C3H10T1/2 cells have a mesenchymal progenitor cell phenotype and as such do not express type X collagen (first lane from left). Addition of BMP-2 to normal, uninfected C3H10T $\frac{1}{2}$ cells induces differentiation into mature chondrocytes and expression of type X collagen (compare first and second lanes from left), whereas addition of BMP-2 to vaccinia infected C3H10T $\frac{1}{2}$ cells fails to induce synthesis of type X collagen (third lane from left). In the presence of 2mM HU, BMP-2 induces

type X collagen synthesis even in vaccinia virus infected C3H10T ½ cells (fourth lane from left).

- [0363] This strategy for attenuating viral cytopathic effects is applicable to other viruses, other cell types and to selection of immunoglobulin molecules that, for example, induce apoptosis upon cross-linking.

EXAMPLE 12

Construction of Human Fab Fragment Libraries of Diverse Specificity

- [0364] Libraries of polynucleotides encoding fully human, diverse immunoglobulin Fab fragments are produced as follows. These Fab fragments comprise a heavy chain variable region linked to a first constant region domain (VH-CH1) paired with an immunoglobulin light chain. Genes for human VH (variable region of heavy chain), VK (variable region of kappa light chain) and VL (variable region of lambda light chains) are amplified by PCR. For each of the three variable gene families, both a recombinant plasmid library and a vaccinia virus library is constructed. The variable region genes are inserted into a p7.5/tk-based transfer/expression plasmid immediately upstream of a constant region sequence corresponding to the CH1 domain of heavy chains or the kappa light chain constant region, CK. These plasmids are employed to generate the corresponding vaccinia virus recombinants by trimolecular recombination and can also be used directly for high level expression of Fab fragments following transfection of one immunoglobulin chain or fragment thereof into cells infected with vaccinia virus recombinants of a second immunoglobulin chain or fragment thereof. The two chains are synthesized and assembled to form an Fab fragment. These Fab fragments may be membrane bound or secreted by attaching coding sequences for signal sequences, transmembrane domains, and/or intracellular domains, as is understood by one of ordinary skill in the art.

- [0365] 12.1 pVHEc. An expression vector which encodes a human heavy chain fragment comprising VH and the CH1 domain of C μ , designated pVHEc, is

constructed as follows. Plasmid p7.5/tk2 is produced as described in Example 1.1, *supra*. A DNA construct encoding amino acids 109-113 of VH and the CH1 domain, *i.e.*, amino acids 109-223B of C μ , is amplified from the IgM heavy chain gene isolated as described in Example 1, and is modified by PCR to include a BstEII site at the 5' end of the region encoding amino acids 109-113+ the C μ CH1 domain, and a stop codon and a SalI site at its 3' end. This DNA is inserted into p7.5/tk2 between the BstEII and SalI sites to generate pVHEc. Heavy chain variable region (VH) PCR products (amino acids (-4) to(110)), produced as described in Example 1.4(a), using the primers listed in Tables 1 and 2, are cloned into BssHII and BstEII sites. Because of the overlap between the CH1 domain sequence and the restriction enzyme sites selected, this results in construction of a contiguous heavy chain fragment which lacks a functional signal peptide but remains in the correct translational reading frame.

[0366] 12.2 pVKEc and pVLEc. Expression vectors encoding the human κ and λ immunoglobulin light chain constant regions, designated herein as pVKEc and pVLEc, are constructed as follows. Plasmid p7.5/tk3.1, is produced as described in Example 1.3, *supra*.

[0367] (a) Plasmid p7.5/tk3.1 is converted into pVKEc by the following method. A cDNA coding for the C κ region is isolated as described in Example 1, with primers to include an XhoI site at the 5' end of the region encoding amino acids 104-107+C κ , and a stop codon and a SalI site at its 3' end, which is then cloned into p7.5/tk3.1 at XhoI and SalI sites to generate pVKEc. Kappa light chain variable region (VK) PCR products (amino acids(-3) to(105)), produced as described in Example 1.4(b), using the primers listed in Tables 1 and 2, are then cloned into pVKEc at the ApaLI and XhoI sites. Because of the overlap between the κ light chain sequence and the restriction enzyme sites selected, this results in construction of contiguous κ light chains which lacks a functional signal peptide but remains in the correct translational reading frame.

[0368] (b) Plasmid p7.5/tk3.1 is converted into pVLEc by the following method. A cDNA coding for the C λ region is isolated as described in Example 1, with primers to include a HindIII site and amino acids 105 to 107 of V λ at its 5'

end and a stop codon and a SalI site at its 3' end, which is then cloned into p7.5/tk3 at HindIII and SalI sites to generate pVLEc. Lambda light chain variable region (VL) PCR products (amino acids(-3) to(104)), produced as described in Example 1.4(c), using the primers listed in Tables 1 and 2, are then cloned into pVLEc at ApaLI and HindIII sites. Because of the overlap between the λ light chain sequence and the restriction enzyme sites selected, this results in construction of contiguous λ light chains which lacks a functional signal peptide but remains in the correct translational reading frame.

[0369] 12.3 Secreted or Membrane Bound Forms of Fab. The expression vectors (pVHEc, pVKEc and pVLEc) serve as prototype vectors into which secretion signals, transmembrane domains, cytoplasmic domains, or combinations thereof can be cloned to target Fab to the cell surface or the extracellular space. These signals and domains, examples of which are shown in Table 7, may be inserted either in the N-terminus of Fab between NcoI and BssHII of pVHEc (or NcoI and ApaLI of pVKEc and pVLEc) and/or in the C-terminus at SalI site. To target an Fab for secretion into the extracellular compartment, a signal peptide is inserted at the N-terminus of either or both Fab chains, VH-CH1 or light chain. To anchor an Fab in the plasma membrane for extracellular presentation, a transmembrane domain is added to the carboxyl-terminus of VH-CH1 chain and/or to the light chain. A cytoplasmic domain may also be added.

Table 7. Localization signals			
Signal sequence	Terminus	Location	Protein
MGWSCILFLVATATGAHS (SEQ ID NO:146)	N	ES	IgG1
NLWTTASTFIVLFLLSLFYSTTVTLF (SEQ ID NO:147)	C/N	PM	IgM

Abbreviations for items under Location: ES, extracellular space; PM, plasma membrane.

EXAMPLE 13

Construction of Human Single-Chain-Fv (ScFv) Antibody Libraries.

[0370] 13.1 Human scFv expression vectors p7.5/tk3.2 and p7.5/tk3.3 are constructed by the following method, as illustrated in Figure 10. Plasmid p7.5/tk3 is produced as described in Example 1.3, *supra*. Plasmid p7.5/tk3 is converted to p7.5/tk3.1 by changing the four nucleotides ATAC between NcoI and ApaLI sites into ATAGC, so that the ATG start codon in NcoI is in-frame with ApaLI without the inserted signal peptide. This is conveniently accomplished by replacing the NotI-to-SalI cassette described in Example 1.3 (SEQ ID NO:29) with a cassette having the sequence 5'-GCGGCCGCCC ATGGATAGCG TGCACCTGAC TCGAGAAGCT TAGTAGTCGA C-3', referred to herein as SEQ ID NO:112.

[0371] Plasmid p7.5/tk3.1 is converted to p7.5/tk3.2 by substituting the region between XhoI and SalI (*i.e.*, nucleotides 30 to 51 of SEQ ID NO:112), referred to herein as SEQ ID NO:113, with the following cassette: XhoI-(nucleotides encoding amino acids 106-107 of V_K)-(nucleotides encoding a 10 amino acid linker)-G-BssHII-ATGC-BstEII-(nucleotides encoding amino acids 111-113 of V_H)-stop codon-SalI. This is accomplished by digesting p7.5/tk3.1 with XhoI and SalI, and inserting a cassette having the sequence 5'-CTCGAGAT CAAAGAGGGT AAATCTTCCG GATCTGGTTC CGAAGGCGCG CATGCGGTCA CCGTCTCCTC ATGAGTCGAC 3', referred to herein as SEQ ID NO:114. The linker between V_K and V_H will have a final size of 14 amino acids, with the last 4 amino acids contributed by the V_H PCR products, inserted as described below. The sequence of the linker is 5'-GAG GGT AAA TCT TCC GGA TCT GGT TCC GAA GGC GCG CAC TCC 3' (SEQ ID NO:115), which encodes amino acids EGKSSGSGSEGAHS (SEQ ID NO:116).

[0372] Plasmid p7.5/tk3.1 is converted to p7.5/tk3.3 by substituting the region between HindIII and SalI (*i.e.*, nucleotide 36 to 51 of SEQ ID NO: 112), referred to herein as SEQ ID NO:117, with the following cassette: HindIII-(nucleotides

encoding amino acid residues 105-107 of V λ)-(nucleotides encoding a 10 amino acid linker)-G-BssHII-ATGC-BstEII-(nucleotides encoding amino acids 111-113 of VH)-stop codon-SalI. This is accomplished by digesting p7.5/tk3.1 with HindIII and SalI, and inserting a cassette having the sequence 5' AAGCTTACCG TCCTAGAGGG TAAATCTTCC GGATCTGGTTC CGAAGGCGCG CATGCGGTCA CCGTCTCCTC ATGAGTCGAC 3' (SEQ ID NO:118). The linker between V λ and VH will have a final size of 14 amino acids, with the last 4 amino acids contributed by the VH PCR products, inserted as described below. The sequence of the linker is 5'GAG GGT AAA TCT TCC GGA TCT GGT TCC GAA GGC GCG CAC TCC 3' (SEQ ID NO:119), which encodes amino acids EGKSSGSGSEGAHS (SEQ ID NO:120).

[0373] 13.2 Cytosolic Forms of scFv. Expression vectors encoding scFv polypeptides comprising human κ or λ immunoglobulin light chain variable regions, fused in frame with human heavy chain variable regions, are constructed as follows.

[0374] (a) Cytosolic V κ VH scFv expression products are prepared as follows. Kappa light chain variable region (V κ) PCR products (amino acids(-3) to(105)), produced as described in Example 1.4(b), using the primers listed in Tables 1 and 2, are cloned into p7.5/tk3.2 between the ApaLI and XhoI sites. Because of the overlap between the κ light chain sequence and the restriction enzyme sites selected, this results in construction of a contiguous κ light chain in the same translational reading frame as the downstream linker. Heavy chain variable region (VH) PCR products (amino acids (-4) to(110)), produced as described in Example 1.4(a), using the primers listed in Tables 1 and 2, are cloned between the BssHII and BstEII sites of p7.5/tk3.2 to form complete scFv open reading frames. The resulting products are cytosolic forms of V κ -VH fusion proteins connected by a linker of 14 amino acids. The scFv is also preceded by 6 extra amino acids at the amino terminus encoded by the restriction sites and part of the V κ signal peptide.

[0375] (b) Cytosolic V λ VH scFv expression products are prepared as follows. Lambda light chain variable region (VL) PCR products (amino acids(-3) to(104)), produced as described in Example 1.4(c), using the primers listed in Tables 1 and 2, are cloned into p7.5/tk3.3 between the *Apa*LI and *Hind*III sites. Because of the overlap between the λ light chain sequence and the restriction enzyme sites selected, this results in construction of a contiguous λ light chain in the same translational reading frame as the downstream linker. Heavy chain variable region (VH) PCR products (amino acids (-4) to(110)), produced as described in Example 1.4(a), using the primers listed in Tables 1 and 2, are cloned between *Bss*HII and *Bst*EII sites of p7.5/tk3.3 to form complete scFv open reading frames. The resulting products are cytosolic forms of V λ -VH fusion proteins connected by a linker of 14 amino acids. The scFv is also preceded by 6 extra amino acids at the amino terminus encoded by the restriction sites and part of the V λ signal peptide.

[0376] 13.3 Secreted or Membrane Bound Forms of scFv. The cytosolic scFv expression vectors described in section 13.2 serve as the prototype vectors into which secretion signals, transmembrane domains, cytoplasmic domains, or combinations thereof can be cloned to target scFv polypeptides to the cell surface or the extracellular space. Examples of signal peptides and membrane anchoring domains are shown in Table 7, *supra*. To generate scFv polypeptides to be secreted into the extracellular space, a cassette encoding an in-frame secretory signal peptide is inserted so as to be expressed in the N-terminus of scFv polypeptides between the *Nco*I and *Apa*LI sites of p7.5/tk3.2 or p7.5/tk3.3. To generate membrane-bound scFv for Ig-crosslinking or Ig-binding based selection, in addition to the signal peptide, a cassette encoding the membrane-bound form of C μ is cloned into the C-terminus of scFv between the *Bst*EII and *Sal*I sites, downstream of and in-frame with the nucleotides encoding amino acids 111-113 of VH. A cytoplasmic domain may also be added.

EXAMPLE 14

Construction of Camelized Human Single-Domain Antibody Libraries

[0377] Camelid species use only heavy chains to generate antibodies, which are termed heavy chain antibodies. The poxvirus expression system is amendable to generate both secreted and membrane-bound human single-domain libraries, wherein the human V_H domain is "camelized," *i.e.*, is altered to resemble the V_H domain of a camelid antibody, which can then be selected based on either functional assays or Ig-crosslinking/binding. Human V_H genes are camelized by standard mutagenesis methods to more closely resemble camelid V_H genes. For example, human V_H3 genes, produced using the methods described in Example 1.4 using appropriate primer pairs selected from Tables 1 and 2, is camelized by substituting G44 with E, L45 with R, and W47 with G or I. See, *e.g.*, Riechmann, L., and Muyldermans, S. *J. Immunol. Meth.* 231:25-38. To generate a secreted single-domain antibody library, cassettes encoding camelized human V_H genes are cloned into pVHEs, produced as described in Example 1.2, to be expressed in-frame between the BssHII and BstEII sites. To generate a membrane-bound single-domain antibody library, cassettes encoding camelized human V_H genes are cloned into pVHE, produced as described in Example 1.1, to be expressed in-frame between the BssHII and BstEII sites. Vectors pVHE and pVHEs already have the signal peptide cloned in between the NcoI and BssHII sites. Amino acid residues in the three CDR regions of the camelized human V_H genes are subjected to extensive randomization, and the resulting libraries can be selected in poxviruses as described herein.

EXAMPLE 15

Selection of Fc-modified antibodies for enhanced immune effector functions

[0378] Human monoclonal antibodies are being used in therapeutic applications for treatment of an increasing number of human diseases. Human antibodies may induce or block signaling through specific cell receptors. In some applications, human antibodies may activate any of a variety of accessory effector cells through an interaction between the Fc portion of the antibody molecule and a matching Fc receptor (FcR) on these effector cells. It is, therefore, of considerable interest to identify modifications of immunoglobulin heavy chain constant region sequences that enhance or inhibit binding and signaling through FcR or binding and activation of other mediators of immune effector functions such as components of the complement cascade. See, *e.g.*, U.S. Patent No. 5,624,821; Xu, D., *et al.*, *Cell Immunol* 200:16-26 (2000); and U.S. Patent No. 6,194,551, the disclosures of which are incorporated herein by reference in their entireties.

[0379] One such specific effector function is antibody-dependent cell cytotoxicity (ADCC), a process in which antibody-coated target cells are destroyed by NK cells or other monocytes. ADCC is mediated by antibody molecules with variable region encoded specificity for a surface molecule of a target cell and constant region encoded specificity for FcγRIII on the NK cell. Through analysis of crystal structures and site-directed mutagenesis, it has been determined that the FcγRIII binding site on human IgG1 is localized mainly to the lower hinge, *i.e.*, about amino acids 247-252 of IgG1, and the adjacent CH2 regions. See, *e.g.*, Sarmay G., *et al.*, *Mol Immunol* 29:633-639 (1992); and Michaelsen, T.E., *et al.*, *Mol Immunol* 29:319-26 (1992). By constructing a library of genes encoding antibody molecules with randomly mutated lower hinge regions in a selectable mammalian expression vector, it would be feasible to select specific constant region variants with enhanced function for ADCC. To simplify execution of this strategy, a library is constructed with defined immunoglobulin variable region sequences that confer a desired specificity.

[0380] 15.1. Construction of pVHE-X and pVKE-X or pVLE-X. Plasmid pVHE-X, a human VH expression vector with a defined variable region, designated herein as X, is constructed as follows. The construction is illustrated in Figure 11. An antibody with a defined specificity X is isolated by conventional methods, or is produced and selected in eukaryotic cells using poxvirus vectors, by methods described herein. If necessary, the VH gene of the antibody is subcloned into pVHE, produced as described in Example 1.1, between the BssHII/BstEII sites, resulting in plasmid pVHE-X. Also if necessary, the VK or VL gene of the antibody is subcloned either into pVKE, produced as described in Example 1.3, at the ApaLI/XhoI sites to produce pVKE-X, or into pVLE, produced as described in Example 1.3, at ApaLI/HindIII sites, to produce pVLE-X, respectively.

[0381] 15.2 Isolation of a human C γ 1 cassette. A cDNA coding for the human C γ 1 heavy chain is isolated from bone marrow RNA using SMARTTM RACE cDNA Amplification Kit, using the following primers:

huC γ 1-5B: 5'ATTAGGATCC GGTACCGTC TCCTCAGCC 3' (SEQ ID NO:121)

huC γ 1-3S: 5'ATTAGTCGACTCATTTACCC GGAGACAGGG AGAG 3' (SEQ ID NO:122)

[0382] The PCR product comprises the following elements: BamHI-BstEII- (nucleotides encoding amino acids 111-113 of VH)-(nucleotides encoding amino acids 114-478 of C γ 1)-TGA-SalI. This product is subcloned into pBluescriptII/KS at BamHI and SalI sites, and a second BstEII site corresponding to amino acids 191 and 192 within the CH1 domain of C γ 1 is removed by site-directed mutagenesis without change to the amino acid sequence.

[0383] 15.3 Construction of Fc γ 1 library. C γ 1 variants are generated by overlap PCR by the following method. The BstEII-mutagenized C γ 1 cassette, produced as described in section 15.2, is used as the template. In the first round of PCR, amplifications are carried out in two separate reactions using C γ 1-sense/C γ 1-internal-R and C γ 1-internal-S/C γ 1-reverse primer sets.

Cy1-sense: 5'AATATGGTCACCGTCTCCTCAGCC 3' (SEQ ID NO:123)

Cy1-internal-R: 5'(MNN)₆TTCAGGTGCTGGGCACGG 3' (SEQ ID NO:124)

Cy1-internal-S: 5'(NNK)₆GTCTTCCTCTTCCCCCA 3' (SEQ ID NO:125)

Cy1-reverse: 5'AATATGTCGACTCATTTACCCGG 3' (SEQ ID NO:126)

(M=A+C, K=G+T, N=A+T+G+C)

The Cy1-internal-R and Cy1-internal-S primers have degenerate sequence tails that code for variants of the six amino acids comprising residues 247-252 in the lower hinge. In the second round of PCR, the purified products from the first round are fused by overlap PCR using the Cy1-sense and Cy1-reverse primers.

[0384] The resulting products are approximately 1000 bp in size, and randomly encode all 20 amino acids in each of the six amino acid positions 247-252. The PCR products are digested with BstEII and SalI, and are cloned into BstEII/SalI-digested pVHE-X, produced as described in section 15.1, to generate a library of pVHE-X-γ1 variants. These variants are then introduced into vaccinia virus using trimolecular recombination as described in Example 5. In conjunction with the recombinant vaccinia virus harboring the light chain, the Fcγ1 library will be used to select those Fc variants that confer enhanced ADCC activity on a VHE-X-γ1 expressing antibody.

[0385] 15.4 Other applications. In addition the generation of variants at amino acids 247-252, other residues, such as amino acids 278-282 and amino acids 346-351 of IgG1, are also involved in binding to FcγRIII. Following the identification of Fcγ1 variant in amino acids 247-252 that exhibits an enhanced ADCC activity, the same strategy can be employed to identify additional mutations in the other two regions that exhibit synergistic enhancement of ADCC function.

[0386] The same principle/technique can be applied to identifying variants that confer enhanced effector function on other immunoglobulin heavy chain constant region isotypes that bind to different Fc receptors. In preferred embodiments the

receptors to be targeted include FcγRI (CD64), FcγRII-A (CD32), FcγRII-B1, FcγRII-B2, FcγRIII (CD16), and FcεRI. In other preferred embodiments, variants may be selected that enhance binding of complement components to the Fc region or Fc mediated binding to placental membrane for transplacental transport.

EXAMPLE 16

Construction of heavy chain fusion proteins to facilitate selection of cells infected with specific immunoglobulin gene recombinant vaccinia virus

[0387] 16.1 Construction of CH1-Fas. An expression vector which encodes a fusion protein comprising the human heavy chain CH1 domain of Cμ, fused to the transmembrane and death domains of Fas, designated herein as CH1-Fas, is constructed by the following method. The fusion protein is illustrated in Fig. 13(a).

[0388] Plasmid pVHE, produced as described in Example 1.1, is digested with BstEII and SalI and the smaller DNA fragment of about 1.4 Kb is gel purified. This smaller fragment is then used as a template in a PCR reaction using forward primer CH1(F) – 5' ACACGGTCAC CGTCTCCTCA GGGAGTGC 3' (SEQ ID NO:127) and reverse primer CH1(R) 5'AGTTAGATCT GGATCCTGGA AGAGGCACGT T 3' (SEQ ID NO:128). The resulting PCR product of about 320 base pairs is gel purified.

[0389] A DNA fragment comprising the transmembrane and death domains of Fas is amplified from plasmid pBS-APO14.2 with forward primer FAS(F) 5' AACGTGCCTC TTCCAGGATC CAGATCTAAC 3' (SEQ ID NO:129) and reverse primer FAS(R) 5'ACGCGTCGAC CTAGACCAAG CTTTGGATTTCAT 3'(SEQ ID NO:130). The resulting PCR product of about 504 base pairs is gel purified.

[0390] The resulting 320 and 504-base pair fragments are then combined in a PCR using forward primer CH1(F) and reverse primer FAS (R), to produce a fusion fragment of about 824 base pairs. This fragment is digested with BstEII

and SalI, and the resulting 810-base pair fragment is gel purified. Plasmid pVHE also digested with BstEII and SalI, and the larger resulting fragment of about 5.7 Kb is gel purified. These two BstEII/SalI fragments are then ligated to produce CH1-Fas.

[0391] 16.2 Construction of CH4-Fas. An expression vector which encodes a fusion protein comprising the human heavy chain CH1-CH4 domains of $C\mu$, fused to the transmembrane and death domains of Fas, designated herein as CH4-Fas, is constructed by the following method. The fusion protein is illustrated in Fig. 13(b).

[0392] Plasmid pVHE, produced as described in Example 1.1, is digested with BstEII and SalI and the smaller DNA fragment of about 1.4 Kb is gel purified. This smaller fragment is then used as a template in a PCR reaction using forward primer CH4(F) 5'CTCTCCCGCG GACGTCTTCG T 3' (SEQ ID NO:131) and reverse primer CH4(R) 5'AGTTAGATCT GGATCCCTCA AAGCCCTCCT C 3' (SEQ ID NO:132). The resulting PCR product of about 268 base pairs is gel purified.

[0393] A DNA fragment comprising the transmembrane and death domains of Fas is amplified from plasmid pBS-APO14.2 with forward primer FAS(F2)-5'GAGGAGGGCTTTGAGGGATC CAGATCTAAC 3' (SEQ ID NO:133) and reverse primer FAS(R), as shown in section 16.1. The resulting PCR product of about 504 base pairs is gel purified.

[0394] The resulting 268 and 504-base pair fragments are then combined in a PCR using forward primer CH4(F) and reverse primer FAS (R), to produce a fusion fragment of about 765 base pairs. This fragment is digested with SacII and SalI, and the resulting 750-base pair fragment is gel purified. Plasmid pVHE also digested with SacII and SalI, and the larger resulting fragment of about 6.8 Kb is gel purified. These two SacII/SalI fragments are then ligated to produce CH4-Fas.

[0395] 16.3 Construction of CH4(TM)-Fas. An expression vector which encodes a fusion protein comprising the human heavy chain CH1-CH4 domains

and the transmembrane domain of $C\mu$, fused to the death domain of Fas, designated herein as CH4(TM)-Fas, is constructed by the following method. The fusion protein is illustrated in Fig. 13(c).

[0396] Plasmid pVHE, produced as described in Example 1.1, is digested with BstEII and SalI and the smaller DNA fragment of about 1.4 Kb is gel purified. This smaller fragment is then used as a template in a PCR reaction using forward primer CH4(F) as shown in section 16.2, and reverse primer CH4(R2) 5' AATAGTGGTG ATATATTTCA CCTTGAACAA 3' (SEQ ID NO:134). The resulting PCR product of about 356 base pairs is gel purified.

[0397] A DNA fragment comprising the death domains of Fas is amplified from plasmid pBS-APO14.2 with forward primer FAS(F3)- 5'TTGTTCAAGG TGAAAGTGAA GAGAAAGGAA 3' (SEQ ID NO:135) and reverse primer FAS(R), as shown in section 16.1. The resulting PCR product of about 440 base pairs is gel purified.

[0398] The resulting 356 and 440-base pair fragments are then combined in a PCR using forward primer CH4(F) and reverse primer FAS (R), to produce a fusion fragment of about 795 base pairs. This fragment is digested with SacII and SalI, and the resulting 780-base pair fragment is gel purified. Plasmid pVHE also digested with SacII and SalI, and the larger resulting fragment of about 6.8 Kb is gel purified. These two SacII/SalI fragments are then ligated to produce CH4(TM)-Fas.

[0399] 16.4 Cloning and insertion of diverse VH genes into the Ig-Fas fusion proteins. Heavy chain variable region (VH) PCR products (amino acids (-4) to(110)), produced as described in Example 1.4(a), using the primers listed in Tables 1 and 2, are cloned into BssHII and BstEII sites of CH1-Fas, CH4-Fas and CH4(TM)-Fas. Because of the overlap between the CH1 domain sequence and the restriction enzyme sites selected, this results in construction of a contiguous heavy chain fragment which lacks a functional signal peptide but remains in the correct translational reading frame.

EXAMPLE 17

Generation of Ig α and Ig β -expressing HeLaS3 and COS7 cell lines

[0400] In order to express specific human monoclonal antibodies on the cell surface, heavy and light chain immunoglobulins must physically associate with other proteins in the B cell receptor complex. Therefore, in order for host cells to be able to express the human antibody library they must be able to express the molecules and structures that are necessary for the efficient synthesis and assembly of antibodies into membrane-bound receptors. Mouse lymphoma cells express the molecules and structures that are necessary for the expression of specific human antibodies on the cell surface. However, one disadvantage of using lymphoma cells for human antibody library expression is that endogenously expressed immunoglobulin heavy and/or light chains can co-assemble with transgenic immunoglobulin chains, resulting in the formation of nonspecific heterogeneous molecules, which dilute antigen-specific receptors. Another disadvantage of using mouse lymphoma cells to express the human antibody library is that vaccinia virus replicates poorly in lymphocytic cell lines. Therefore, preferred cell types for the expression of specific human antibodies are those which permit the generation of high titers of vaccinia virus and those that are not derived from the B cell lineage. Preferred cell types include HeLa cells, COS7 cells and BSC-1 cells.

[0401] The immunoglobulin heavy and light chains of the B cell receptor physically associate with the heterodimer of the Ig α and Ig β transmembrane proteins (Reth, M. 1992. Annu. Rev. Immunol. 10:97). This physical association is necessary for the efficient transport of membrane-bound immunoglobulin to the cell surface and for the transduction of signals through the B cell receptor (Venkitaraman, A.R. et al., 1991. Nature 352:777). However, it is unclear as to whether Ig α /Ig β heterodimers are necessary and sufficient for the expression of membrane-bound immunoglobulin in heterologous cell lines.

Therefore, the cell surface expression of human antibodies on HeLaS3 and COS7 cells was evaluated following their transfection with human Ig α and Ig β cDNA.

[0402] 17.1 Cloning the human Ig α and Ig β cDNA by PCR.

[0403] cDNA generated from the EBV-transformed human B cells was used as the template in the PCR reactions to amplify human Ig α and Ig β cDNA. Human Ig α cDNA was amplified with the following primers:

ig α 5' – 5'ATTAGAATTCATGCCTGGGGGTCCAGGA3', designated herein as (SEQ ID NO:136); and

ig α 3' – 5'ATTAGGATCCTCACGGCTTCTCCAGCTG3', designated herein as (SEQ ID NO:137).

Human Ig β cDNA was amplified with the following primers:

ig β 5' – 5'ATTAGGATCCATGGCCAGGCTGGCGTTG3', designated herein as (SEQ ID NO:138); and

ig β 3' – 5'ATTACCAGCACACTGGTCACTCCTGGCCTGGGTG3', designated herein as (SEQ ID NO:139).

[0404] Products from Ig α PCR reaction were cloned into pIRESneo expression vector (Clontech) at EcoRI and BamHI sites, while those from Ig β PCR reaction were cloned into pIREShyg vector (Clontech) at BamHI and BstXI sites. The identities of the cloned Ig α and Ig β were confirmed by DNA sequencing.

[0405] 17.2 Establishing Ig α and Ig β -expressing HeLaS3 and COS7 stable transfectants. HeLaS3 and COS7 cells (1×10^6 per well in a 6-well plate) were transfected with 0.5 to 1 μ g each of the purified pIRESneo-Ig α and pIREShyg-Ig β plasmid DNA using the LIPOFECTAMINE PLUS Reagent (Life technologies). Starting two days later, cells were selected with G418 (at 0.4 mg/ml) and hygromycin B (at 0.2 mg/ml) for about 2 weeks. Drug-resistant HeLaS3 colonies were directly isolated and COS7 transfectants were cloned by limiting dilution. The expression of Ig α and Ig β in each of these clones was then analyzed by RT-PCR, and the results from the representative clones were as shown in Figure 14.

EXAMPLE 18

Construction of a Diverse Library of High Affinity Human Antibodies

[0406] The current invention is the only available method for the construction of a diverse library of immunoglobulin genes in vaccinia or other pox viruses. The vaccinia vector can be designed to give high levels of membrane receptor expression to allow efficient binding to an antigen coated matrix. Alternatively, the recombinant immunoglobulin heavy chain genes can be engineered to induce apoptosis upon crosslinking of receptors by antigen. Since vaccinia virus can be readily and efficiently recovered even from cells undergoing programmed cell death, the unique properties of this system make it possible to rapidly select specific human antibody genes.

[0407] Optimal immunoglobulin heavy and light chains are selected sequentially, which maximizes diversity by screening all available heavy and light chain combinations. The sequential screening strategy is to at first select an optimal heavy chain from a small library of 10^5 H-chain recombinants in the presence of a small library of 10^4 diverse light chains. This optimized H-chain is then used to select an optimized partner from a larger library of 10^6 to 10^7 recombinant L-chains. Once an optimal L-chain is selected, it is possible to go back and select a further optimized H-chain from a larger library of 10^6 to 10^7 recombinant H-chains. This reiteration is a boot-strap strategy that allows selection of a specific high-affinity antibody from as many as 10^{14} H_2L_2 combinations. In contrast, selection of single chain Fv in a phage library or of Fab comprised of separate VH-CH1 and VL-CL genes encoded on a single plasmid is a one step process limited by the practical size limit of a single phage library – perhaps 10^{11} phage particles.

[0408] Since it is not feasible to screen 10^{14} combinations of 10^7 H chains and 10^7 L chains, the selection of optimal H chains begins from a library of 10^5 H chain vaccinia recombinants in the presence of 10^4 L chains in a non-infectious vector.

These combinations will mostly give rise to low affinity antibodies against a variety of epitopes and result in selection of *e.g.*, 1 to 100 different H chains. If 100 H chains are selected for a basic antibody, these can then be employed in a second cycle of selection with a larger library of 10^6 or 10^7 vaccinia recombinant L chains to pick 100 optimal L chain partners. The original H chains are then set aside and the 100 L chains are employed to select new, higher affinity H chains from a larger library of 10^6 or 10^7 H chains.

[0409] The strategy is a kind of in vitro affinity maturation. As is the case in normal immune responses, low affinity antibodies are initially selected and serve as the basis for selection of higher affinity progeny during repeated cycles of immunization. Whereas higher affinity clones may be derived through somatic mutation in vivo, this in vitro strategy achieves the same end by the re-association of immunoglobulin chains. In both cases, the partner of the improved immunoglobulin chain is the same as the partner in the original lower affinity antibody.

[0410] The basis of the strategy is leveraging the initial selection for a low affinity antibody. It is essential that a low affinity antibody be selected. The vaccinia-based method for sequential selection of H and L chains is well-suited to insure that an initial low affinity selection is successful because it has the avidity advantage that comes from expressing bivalent antibodies. In addition, the level of antibody expression can be regulated by employing different promoters in the vaccinia system. For example, the T7 polymerase system adapted to vaccinia gives high levels of expression relative to native vaccinia promoters. Initial rounds of selection can be based on a high level T7 expression system to insure selection of a low affinity "basic antibody" and later rounds of selection can be based on low level expression to drive selection of a higher affinity derivative.

[0411] An outline of a method of the current invention for the construction of a diverse library of immunoglobulin genes in vaccinia is as follows:

1. An immunoglobulin membrane associated heavy chain cDNA library is constructed from human lymphocytes in a *vaccinia* virus vector according to the methods described herein. Specially engineered cells, for example CH33 cells, mouse myeloma cells, and human EBV transformed cell lines or, preferably, HeLa cells and other non-lymphoid cells that do not produce a competing immunoglobulin chain and efficiently support *vaccinia* replication, are infected with the virus library at dilutions such that on average each cell is infected by one viral immunoglobulin heavy chain recombinant.
2. These same cells are also infected with psoralin inactivated immunoglobulin light chain recombinant *vaccinia* virus from an immunoglobulin light chain library constructed in the same *vaccinia* virus vector. Alternatively, the cells may be transfected with immunoglobulin light chain recombinants in a plasmid expression vector. In the population of cells as a whole, each heavy chain can be associated with any light chain.
3. The cells are incubated for a suitable period of time to allow optimal expression of fully assembled antibodies on the cell surface. When the host cell is not of lymphoid origin, the efficiency of membrane antibody expression is enhanced by employing host cells for example, Hela or Cos 7 cells, that have been stably transfected with genes or cDNA expressing Ig α and Ig β proteins.
- 4a. The antigen of interest is bound to inert beads, which are then mixed with the library of antibody expressing cells. Cells that bind to antigen-coated beads are recovered and the associated immunoglobulin heavy chain recombinant virus is extracted.
- 4b. Alternatively, a fluorescence tag is linked, directly or indirectly, to the antigen of interest. Antibody expressing cells which bind the antigen are recovered by Fluorescence Activated Cell Sorting.

4c. Alternatively, host cells may be employed in which cross-linking of the antibody receptor with the antigen induces cell death. This may occur naturally in host cells that are immature cells of the B cell lineage or it may be a consequence of incorporation of a Fas encoded death domain at the carboxyl terminus of the immunoglobulin heavy chain constant region. The lysed cells are separated from the living cells and the recombinant viruses carrying the relevant immunoglobulin heavy chains are extracted.

5. The above cycle, steps 1-4, may be repeated multiple times, isolating recombinant virus each time and further enriching for heavy chains that contribute to optimal antigen binding.

6. Once specific antibody heavy chains have been selected, the entire procedure is repeated with an immunoglobulin light chain cDNA library constructed in the proprietary vaccinia vector in order to select the specific immunoglobulin light chains that contribute to optimal antigen binding. Sequential selection of heavy and light chains maximizes diversity by screening all available heavy and light chain combinations. The final MAb product is optimized by selection of a fully assembled bivalent antibody rather than a single chain Fv or monomeric Fab.

7. The MAb sequence is determined and specific binding verified through standard experimental techniques.

[0412] The final Mab product is optimized by selection of a fully assembled bivalent antibody rather than a single chain Fv. That is, selection is based on bivalent (H_2L_2) antibodies rather than scFv or Fab fragments. Synthesis and assembly of fully human, complete antibodies occurs in mammalian cells allowing immunoglobulin chains to undergo normal post-translational modification and assembly. Synthesis and assembly of complete antibodies would likely be very inefficient in bacterial cells and many specificities are lost due to failure of many antibodies to fold correctly in the abnormal physiological environment of a bacterial cell.

[0413] A relatively wide range of antibody epitope specificities can be selected, including the selection of specificities on the basis of functional activity. Specifically, antibodies can be selected on the basis of specific physiological effects on target cells (e.g., screening for inhibition of TNF-secretion by activated monocytes; induction of apoptosis; etc.) An outline of the method for screening for specific Mab on the basis of a functional assay is as follows:

1. An immunoglobulin heavy chain cDNA library in secretory form is constructed from naïve human lymphocytes in a *vaccinia* virus vector prepared according to the methods described herein. Multiple pools of, for example, about 100 to about 1000 recombinant viruses, are separately expanded and employed to infect producer cells at dilutions such that on average each cell is infected by one immunoglobulin heavy chain recombinant virus. These same cells are also infected with psoralin inactivated immunoglobulin light chain recombinant vaccinia virus from an immunoglobulin light chain library constructed in the same vaccinia virus vector. Alternatively, the infected cells may be transfected with immunoglobulin light chain recombinants in a plasmid expression vector. In the population of cells as a whole, each heavy chain can be associated with any light chain.
2. Infected cells are incubated for a time sufficient to allow secretion of fully assembled antibodies.
3. Assay wells are set up in which indicator cells of functional interest are incubated in the presence of aliquots of secreted antibody. These might, for example, include activated monocytes secreting TNF α . A simple ELISA assay for TNF α may then be employed to screen for any pool of antibodies that includes an activity that inhibits cytokine secretion.
4. Individual members of the selected pools are further analyzed to identify the relevant immunoglobulin heavy chain.

5. Once specific antibody heavy chains have been selected, the entire procedure is repeated with an immunoglobulin light chain cDNA library constructed in the proprietary *vaccinia* vector in order to select specific immunoglobulin light chains that contribute to optimal antigen binding.
6. The MAb sequences are identified and specific binding verified through standard experimental techniques. Because functional selection does not require *a priori* knowledge of the target membrane receptor, the selected Mab is both a potential therapeutic and a discovery tool to identify the relevant membrane receptor.

[0414] Selection occurs within human cell cultures following random association of immunoglobulin heavy and light chains. As noted above, this avoids repertoire restrictions due to limitations of synthesis in bacteria. It also avoids restrictions of the antibody repertoire due to tolerance to homologous gene products in mice. Mouse homologs of important human proteins are often 80% to 85% identical to the human sequence. It should be expected, therefore, that the mouse antibody response to a human protein would primarily focus on the 15% to 20% of epitopes that are different in man and mouse. This invention allows efficient selection of high affinity, fully human antibodies with a broad range of epitope specificities. The technology is applicable to a wide variety of projects and targets including functional selection of antibodies to previously unidentified membrane receptors with defined physiological significance.

[0415] The present invention is not to be limited in scope by the specific embodiments described which are intended as single illustrations of individual aspects of the invention, and any constructs, viruses or enzymes which are functionally equivalent are within the scope of this invention. Indeed, various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

